THE APRIL SCIENTIFIC MONTHLY

EDITED BY J. MCKEEN CATTELL

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THE SCIENTIFIC MONTHLY

APRIL, 1938

LIFE IN THE SEA

By Dr. R. E. COKER

PROFESSOR OF ZOOLOGY AND CHAIRMAN OF THE DIVISION OF THE NATURAL SCIENCES, UNIVERSITY OF NORTH CAROLINA

> And know, moreover, that all that is on the land, in comparison with what is in the sea, is a very small matter. (Jullanár to King Sháh Zemán).

CONDITIONS OF LIFE IN THE SEA[1]

SIZE AND CONTINUITY

FEATURES of the seas that first command attention are their sizes and their continuity. The combined area of the oceans is more than twice that of the lands and their mean depth (3,500 m. or 11,500 ft.) more than four times the mean elevation of the land (700 m. or 2,300 ft.); hence, if all the land were submerged in the sea, such a cataclysm would, after all, cause the displacement of only a relatively small volume of the water. The surface of the earth might indeed be said to be covered with a continuous layer of water from which emerge larger or smaller parts of the solid crust in the form of isolated continents and islands. The isolation of the bodies of land contrasts, therefore, with the continuity of the bodies of sea water, and, if we turn attention to bodies of fresh water in the form of lakes and streams, we find still greater degrees of isolation. Just as the lands are separated from one another by the much larger oceans, so the lakes and ponds and rivers are separated from each other by the greater areas of land. Within a continent or an island there is continuity of land, but continuity of fresh waters is limited to those of a single system or basin, several or many of which are found on any given land mass.

[1] This paper has developed somewhat gradually in connection with the author's teaching of classes in hydrobiology. Kind friends who have read the manuscript at various stages have suggested its publication. It requires some temerity even to approach the large task of compressing into a small space a comprehensive but necessarily incomplete picture of the great complex of environmental conditions surrounding and governing the lives of individual plants and animals in the sea and controlling the evolution of life in the mother waters. The author has simply felt that this ought to be done—not for the benefit of oceanographers, but rather for all who are interested in the conditions of organic life as it is lived in the greater part of the biosphere. Since the readers, if any, are terrestrial, we have made it a point frequently to emphasize the contrast between the surroundings and problems of organisms in the sea as compared with those of organisms living on land or in fresh water. Obviously the paper is a compilation. We may have erred in giving credit in some places when we could not give it in all; therefore, to any one who may find his ideas or information borrowed without express credit we extend a sincere apology in advance. We are indebted to Dr. W. C. Allee, University of Chicago, and Messrs. H. R. Seiwell and Columbus Iselin, of the Woods Hole Oceanographic Institute, for reading the manuscript and offering certain suggestions; but for any shortcomings in the selection or presentation of material the author must accept entire responsibility. The figures adapted from Murray and Hjort, "The Depths of the Ocean," are used by permission of The Macmillan Company, Publishers.

The contrasting aspects of continuity and isolation have marked biological significance. For an animal or a plant the several systems of fresh water, even though comparatively close together geographically, may be widely separated the one from the other by almost insuperable barriers of land, salt water or atmosphere. In the State of New York, for example, the passage from Lake Chautauqua of the Mississippi drainage to Lake Seneca of the Middle Atlantic drainage involves a journey of about 125 miles by land or air but one of several thousand miles by water, fresh and salt—down the Mississippi, across the Gulf of Mexico, up the Atlantic Ocean and the Susquehanna River. The journey from Lake Chautauqua to Lake Erie, only about 8 miles by land or air, once represented (before the construction of the Chicago drainage canal) a path by water even longer than that to Seneca Lake, or nearly a fourth of the distance around the earth at the equator. Notwithstanding the continuity of the oceans, there still exist some effective barriers to the free migration of animals and plants—barriers of temperature, of depth and pressure and of character of bottom or of food supply. Perhaps there are also less prominent barriers of salinity, but chemical barriers in the seas are based on degree of concentration rather than on different combinations of mineral substances such as distinguish different fresh waters or soils. The barriers that exist within the ocean are, then, of the sort that we would call "intangible," as contrasted with the more prominent and abrupt barriers that may bar the free movement of fresh-water or terrestrial animals and plants.

The oceans are not alike, of course. It is not only that Arctic and Antarctic waters are extremely different in temperature and dissolved gases from tropical waters of Atlantic, Pacific and Indian Oceans, but that the several oceans are different in corresponding latitudes. Geologic events and the distribution of continents and islands, as they influence the movements of currents, must have profound effects on the physical and biological conditions in the several oceans and in their various parts. The coastal contacts of Atlantic and Pacific are markedly different, as a glance at the map will show. "The Pacific is bounded everywhere by steep slopes, rising abruptly from profound ocean depths to lofty lands crowned with mountain ranges parallel to its shores and surrounding its whole area. . . ." "'This mountain ring,' as Charles Lapworth said, 'is ablaze with volcanoes and creeping with earthquakes, testifying that it has been recently formed and is still unfinished.'" (Watts, 1935). Almost everywhere the continents present a very different sort of front to the Atlantic, with, generally, a broader continental slope. Watts has interestingly suggested that the Atlantic has been formed by a splitting of a greater continent, and the slow drifting apart of the Americas on the one side and Europe and Africa on the other—a highly theoretical assumption, of course.

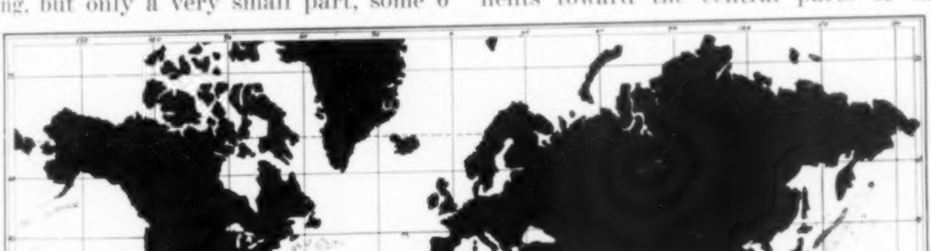
Without going into details, even if the space or our capacity permitted, it is adequate for our present purpose to give warning, as it were, that the conditions of life and the composition of the organic communities are very different in the several oceans and, in consequence of this and other conditions, the constitution of organic deposits on the bottom are distinctive of different regions. The Atlantic and the Pacific, for example, are different oceans, biologically as well as geographically. Assuming, however, that an animal was broadly tolerant of temperature conditions, as some of the whales may be, it could wander at will over the greater part of the surface of the globe. Assuming, again, that an animal were capable of adapting itself to great extremes of pressure and to foregoing the

presence of sunlight, as may be the case with some copepods and other invertebrates, it could find practically constant conditions of temperature in travel from the Arctic across the equator to the Antarctic in either ocean. We need not, however, overstrain the imagination by assuming that any invertebrate animal could accomplish such a journey in its lifetime.

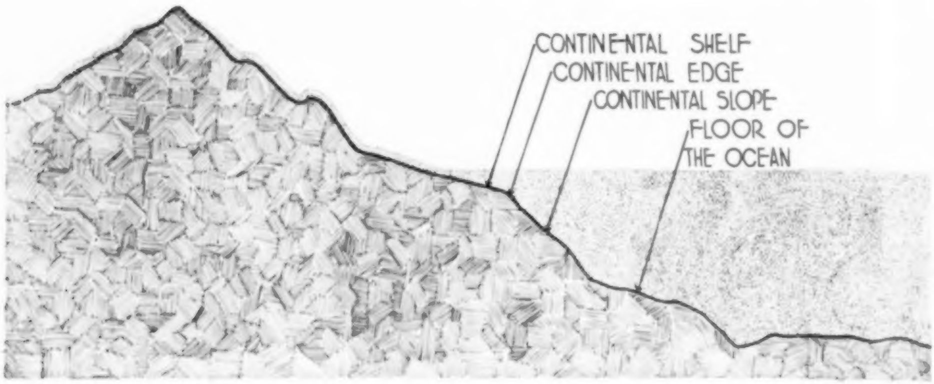
The distinctiveness of different regions of the sea, whether viewed horizontally or vertically, is well reflected in the fact that knowledge of currents and drifts is generally found not so much by the use of current meters as by study of the salinities, temperatures, dissolved gas contents or plankton. Whence comes the water of a particular place and time is often discoverable by chemical and biological analysis.

Depth and Topography

In respect to depth and topography the greater part of the sea is below two thousand fathoms, or 4,000 m., roughly speaking, but only a very small part, some 6 per cent., is below three thousand fathoms (about 3½ miles, or some 6,000 m.). Areas of greater depth than three thousand fathoms are known as "deeps." There is no great difference between the greatest height of the land (Mt. Everest, 29,002 ft.) and the greatest sounded depth of the sea (32,049 ft. or about six standard miles, in the Swire Deep off Mindanao in the Philippines). The largest and one of the deepest is Tuscarora Deep, a little east of Japan; in all at least fifty-seven deeps have been mapped. The bottom of the sea lying between two and three thousand fathoms, is generally an undulating plain with slopes that are usually, but not invariably, gentle. Some of the deeps have high cone-like elevations rising from their centers, with slopes of about 35°—comparable in inclination to a steep mountain side; these, with narrow tops that may be only some fifty meters below the surface of the ocean, are thought to represent submarine volcanic peaks. Proceeding from the shores of the continents toward the central parts of the



DISTRIBUTION OF THE "DEEPS"
INDICATED BY STIPPLING, OR AREAS EXCEEDING 3,000 FATHOMS IN DEPTH.
(AFTER MURRAY AND HJORT).



SCHEMATIC REPRESENTATION OF THE DISPARITY OF THE RESPECTIVE DEPTHS OF THE BIOSPHERE ON LAND AND IN THE SEA

HABITABLE REGIONS (THE BIOSPHERE) INDICATED BY STIPPLING. THE SCALE IS UNAVOIDABLY MISLEADING, SINCE THE STIPPLED AREA OVER LAND REPRESENTS A ZONE WITH DEPTH OF THE ORDER OF 30 METERS, WHILE THE SEA HAS A MEAN DEPTH OF SOME 4,000 METERS. SOME PROMINENT TOPOGRAPHIC FEATURES ARE ALSO SHOWN.

oceans there are commonly distinguishable, first, the *Continental Shelf*, with generally very gentle inclination but with many deep gorges and extending for a greater or less distance to the *Continental Edge* at about one hundred fathoms, and beyond this the much steeper *Continental Slope*, notched by the mouths of the gorges and leading down to the *Floor* of the ocean. On some coasts the Continental Shelf is wanting, as on the western coast of Peru, where the steep slope from the high peaks of the Andes continues almost unbrokenly down to the floor of the ocean below 20,000 ft., giving a continuous incline from peak to deep of some 40,000 ft.

Now, although there is relatively little difference between the greatest height of land and the greatest depth of the sea, there is a vast difference between the thickness of the zones of life on land and in the ocean, respectively. Terrestrial life everywhere occupies a very thin stratum that follows roughly the contours of the land, except at the greatest elevations, while oceanic life extends throughout the space from the surface of the ocean to the bottom, however deep it may be. The thickness of the stratum of life on land, which may roughly be said to extend from the tops of the crowns of the trees to the greatest depths to which their roots penetrate, will not ordinarily exceed 100 ft. or some 30 meters, and the mean thickness would certainly be much less; but if, with some exaggeration, we assume this to be the mean and take the mean depth of the habitable regions of the sea as about 12,000 ft. (about 4,000 meters), and if we remember that the area of the sea is more than twice the area of the land, we find the volume of space available for organic life in the ocean to be some 300 times the space available over the continents and islands. This a very rough sort of calculation, but it indicates at least the order of relative magnitude of the terrestrial and the oceanic communities as a whole.

Interrelation of Sea and Land

Not only are the continents and islands completely surrounded by the continuous sea, but almost all lands everywhere, as a result of weathering processes, are being worn down and washed or blown into the sea. It is estimated that nearly 3 billion metric tons of material from the land is annually being dumped into the sea. In-

deed were there no compensating returns to the land, a few geologic ages might have sufficed to cause the complete disappearance of all dry land. There have been, however, and there must always be such compensating movements, so long as the equilibrium of the crust of the earth is maintained by the gradual elevation, in continental regions, at least, of great areas of sea bottom to become dry land. Enormous terrestrial areas, even the very tops of some of our mountains, are known by their geologic formation and fossils to have been former sea bottoms, to represent, indeed, the repayment of long-term loans from land to sea.

In other ways than through geologic upheavals does the sea regularly contribute to the land. The interrelations are too complex to be analyzed briefly. It may only be suggested that the source of our rain and snow, of the rivers, lakes, springs and ground-waters everywhere is primarily the surface of the sea, where the heat energy of the sun enables the atmosphere to pick up by evaporation the topmost layers of water that may be dropped later upon mountain or plain. Then, too, the climates on land are regulated from the sea in various ways. The winds from the sea are well-known tempering influences, but it is not so generally understood that the great amount of heat energy absorbed by evaporation of the sea water is to a notable extent released by the precipitation that occurs when the warm water-laden breezes are cooled over the land. It is hardly relevant to our purpose to recall that the water powers that operate our lights and engines are giving us merely the energy of the sun that was stored through evaporation, and chiefly at the surface of the sea. In comparison with these contributions from sea to land, the gift to man, bird and other terrestrial animals of a few billion pounds of food and salt seems relatively insignificant, however important and perhaps absolutely essential these materials are to mankind.

THE "CARNEGIE" UNDER SAIL

Chemicals in Solution

Since the sea is the great catch basin for everything that leaches or is washed from the land, as well as for materials that drift in through the atmosphere, and from inter-planetary space, obviously it must be a great chemical potpourri. Doubtless the oceans have in solution every one of the chemical elements, but many of them occur in such slight traces that they can not be detected by ordinary methods of chemical analysis. Indeed there are some elements that, so far, have never been detected in the water but which, nevertheless, are found in marine organisms.[2] Still others are found in animal or plant in greater degrees of concentration than they occur in the water. In separating from the water some of the rarer elements, the protoplasm of the animal or plant is more effective than the most expert chemist. Only a limited number of the elements in solution have presently known biological significance, but some of these, such as iodine, an important component of some seaweeds, and copper, will show only as traces in the reports of chemical analyses. The accompanying Table I reproduces a rather

TABLE I

Analysis of Sea Water*

		gms.	*per cent.*
Sodium chloride	$NaCl$	27.213	77.76
Magnesium chloride	$MgCl_2$	3.807	10.88
Magnesium sulphate	$MgSO_4$	1.658	4.74
Calcium sulphate	$CaSO_4$	1.260	3.60
Potassium sulphate	K_2SO_4	0.863	2.46
Calcium carbonate	$CaCO_3$	0.123	0.34
Magnesium bromide	$MgBr_2$	0.076	0.22
Total		**35.000**	**100.00**

* From Helland-Hansen in Murray and Hjort, after Dittmar in Challenger Reports.

old-fashioned report of the more abundant substances revealed by analysis, but it must not be understood that the materials occur in just the combinations indicated, for the salts occur in sea water in ionized form and consequently are susceptible of diverse and changing combinations. Sodium, for example, may occur as the ion Na, or in combination with other ions as sodium chloride, sodium carbonate, sodium sulfate and sodium bromide.

The chemical composition of the sea water varies from about 31 to 37.5 parts of mineral salts per thousand of water, depending on evaporation and on admixture of fresh water by rivers and icebergs, but the relative proportions of the several salts is virtually constant. In the words of Bigelow (1931, p. 110): "Whether the sample be taken in the Atlantic, in the Pacific, or in the Indian Ocean, in high latitudes or in low, the total solutes are found to be about 54 per cent. chlorine; about 31 per cent. sodium; about 4 per cent. magnesium; about 1 per cent. potassium; 1 per cent. calcium; and about 0.2 per cent. bromine, with about 8 per cent. of sulfate radicals, about 0.2 per cent. of carbonate radicals. And this uniformity in the relative proportions of the commoner constituents is now so well established that it is customary . . . in practice to employ the concentration of one group of its salts as a dependable index to the total saltness. The variety of conditions and the vast areas throughout which such uniformity prevails makes this one of the outstanding phenomena of geochemistry." It may be added that there is as yet no adequate explanation for the great disproportion in which chlorine and sodium occur in the sea, as compared with other chemical substances currently contributed by the rivers. The region of greatest concentration in the ocean proper is the Sargasso Sea (37.5), that enormous central area of the great North Atlantic eddy, encircled by drifting waters, but itself marked by profound stillness and extreme remoteness from continental influences. Partially enclosed regions of especially high rate of evaporation may have 40 parts per 1,000.

[2] Vanadium in the blood of Ascidians and Holothurians, cobalt in lobsters and mussels, nickel in mollusks and lead in the ash of various marine organisms (Bigelow, 1931, pp. 109–110).

Photo by the author.

IN REGIONS OF UPWELLING

THE NUTRITIVE MATERIAL BROUGHT TO THE SURFACE PROMOTES A LUXURIANT DEVELOPMENT OF MICROSCOPIC PLANTS AND ANIMALS (THE PLANKTON), WHICH MAKES POSSIBLE A DENSE POPULATION OF SMALL FISH AND CRUSTACEA, AND THESE, IN TURN, SUPPORT GREAT NUMBERS OF BIRDS. PELICANS ON THE LOBOS DE AFUERA ISLANDS IN COLD WATERS NEAR THE EQUATOR OFF THE WEST COAST OF PERU.

as in the Persian Gulf, or 46.5 per cent. as in the Red Sea (Hesse), while the Baltic Sea, comparatively isolated as it is, from the open oceans, and receiving heavy contributions of fresh water, may have a salt concentration of less than 10 parts per 1,000.

The comparative uniformity in relative proportions of the dissolved materials in off-shore water may easily be over-emphasized. Substances in solution become directly or indirectly the foods of the organisms that live in the waters, and the abundance of the plants that chiefly appropriate them is very variable with the season. It may well be, then, that the materials that occur in minimal quantities relative to the demand are at times entirely removed from solution, so much so as to place a limit to the development of the organisms that require such substances. Nitrogenous compounds, phosphorus and silica, particularly, are found sometimes to become so depleted as to check the growth of plankton plants. Then some of the dying plants may sink into the deeper layers of water, there to become decomposed and dissolved, yielding up the chemical materials in a region where for lack of light they can not again be immediately utilized. Consequently the plant nutrients tend to become accumulated in the deeper strata while superficial waters become depleted.[3] As Krogh says:

> If no mixing took place the depletion would go on to exhaustion and life would die out except along the coasts, but in certain areas, mainly at fairly high latitudes, but also for

[3] Another phase of the one-directional flow of some of the materials necessary to organic life is suggested by the following comment of Bigelow (1931, pp. 31–32):—"with silica contributed by the rivers to the sea, and with no return loss either to the atmosphere or to the land (except in regions of elevation), it seems that the silica of the earth is now tending to accumulate on the sea floor."

Photo by Coit Coker.

THE WOODS HOLE OCEANOGRAPHIC INSTITUTION AND ITS SHIP, THE "ATLANTIS"

DESIGNED ESPECIALLY FOR EXPLORATION OF THE SEA.

instance in the huge Gulf of Guinea, waters from the deep rise to the surface and become the seat of a large outburst of planktonic life which imparts a distinct tint of green to the water. From these areas of fertility and abundance the waters spread by the currents become progressively poorer in the salts necessary for plant growth, and the life areas of the ocean where the water is of a pure blue can only be compared to deserts supporting a minimum of life.[4]

At best sea water is a very dilute solution of many of the materials, such as phosphates and compounds of nitrogen required for the growth and multiplication of plants; and, of course, the animals are dependent upon the plants. Concentration of some of these food substances in sea water is many times less than in good soil. Correspondingly, marine plants must be adapted to derive nutriment from an extremely weak solution. Put in another way, they must have greatly extended surfaces relative to size of body to permit of a maximum efficiency in absorption through the surface. In short, they must generally be of minute size, since the smaller the body the greater the ratio of surface to volume. In contrast then to the trees, shrubs, weeds and grasses of the land we find the predominant vegetation of the sea in the form of exceedingly minute yellowish and brownish algae such as the diatoms and the more minute Coccolithophoridae.

As Brooks pointed out long ago, it is advantageous for the new plant cells which are formed by cell multiplication to separate from each other as soon as possible in order to expose the whole of their surface to the water. Cell aggregation and specialization in form have not taken place among marine plants in any way comparable to what has occurred with terrestrial vegetation.

In another way, and in further consequence of its chemical surroundings, the marine organism faces a different and simpler problem than does its relative of fresh water or of land. Living continuously immersed in a solution not differing so widely in salt content from its own body fluids, the alga, the protozoan,

[4] Krogh, 1934, pp. 423–424.

the soft-bodied larva or adult of higher groups require relatively little protection against disturbance of the chemical balance, losses to the environment through diffusion or desiccation.

Organic Wastes

On land, leaves, twigs and other parts of plants and the wastes of animals fall a distance of a few feet to the ground to decay and become the nutrients of other plants or to furnish food for small animals or for the bacteria of decomposition, which in turn are eaten by animals. In ponds and lakes the organic wastes likewise accumulate on the bottom and there harbor a luxuriant community of scavenger animals and bacteria. In the great open sea, however, the fall extends through a long distance and since the bodies of the predominant populations of the sea are minute, the rate of sinking is exceedingly slow. Even a large copepod falling at a rate of about one centimeter per second (or a couple of feet a minute) would require a couple of days to reach a depth of a mile, but protozoa, diatoms and coccolithophores must sink at vastly slower rates. Meanwhile, the living animals of intermediate depths are all to be supported and what other source of food than the downfalling bodies is available for such animals? There is also ample time for the dissolution of the small bodies, so that in areas of great depth even calcareous and siliceous skeletons may be completely dissolved before the bottom is reached. It appears that, barring the extensive deposits of skeletons in regions of appropriate depth, there is no great accumulation of solid organic wastes in the depths of the sea.

On the other hand, there is a considerable accumulation of organic matter in solution, which, although in dilute solution, is substantial in amount. Is this material utilized in the depths or does it represent in considerable part an irretrievable loss to the organic world? Krogh (1934) has estimated that the dissolved organic substance is equivalent to some three hundred times the amount of living organic material in the sea at any one time. He calculates that the Atlantic Ocean has dissolved organic matter equal to 20,000 times the world's wheat harvest for one year; he suggests the possibility that this material has "in the main gone out of organic circulation," that it is unrecoverable and is possibly accumulating. We know little, however, of the capacity of bacteria and other organisms of the depths of the sea to utilize the dissolved organic matter.

Pressure

Pressure in the ocean, increasing by one atmosphere for every 33 feet of depth, varies from one atmosphere (15 lbs. per square inch) at the surface to nearly 1,000 atmospheres at the greatest depth. It is obvious, of course, that the greatest difference in pressure to which a terrestrial animal may be subject in passing from the lowest level of exposed land to the top of the loftiest mountain peak or even to the greatest height to which a bird can soar, must be considerably less than one atmosphere. So great is the pressure even at 1,000 meters (a little over 100 atmospheres) that a block of ordinary wood, it is said, would be reduced to half its volume through the squeezing out of air ordinarily imprisoned in the cell spaces and would sink instead of floating; and a similar statement would apply to cork.

It is an old but, as it now seems, a very irrational assumption that the conditions of pressure that prevail in the depth of the sea were inconsistent with the existence of life. An *azoic* area beyond the depth of some 1,800 feet (600 meters) was once conceived to exist. Not only have explorations with deep sea trawls, dredges and plankton nets revealed the falsity of such an assumption, but obviously there was no *a priori* reason for it.

THE "ALBATROSS"—OF THE U. S. BUREAU OF FISHERIES
PROBABLY THE FIRST SHIP DESIGNED FOR EXPLORATION OF THE SEA.

It is a quality of liquid as of gas that pressure at any level is uniformly distributed in all directions. Consequently, for an organism adapted to the pressure, it is no more to be supposed that the animal should suffer from it than that we should be overwhelmed by the atmospheric pressure of some fifteen pounds to the square inch which we endure—let us say, some tens of thousands of pounds of pressure upon the body as a whole.

Nevertheless, the change in pressure with depth does interpose some barrier to the vertical migration of animals. If we suffer in undergoing the relatively slight modification of pressure within the limits of a single atmosphere when we ascend to an elevation of 10,000 or 15,000 feet or descend only a few meters into the water, what must be expected to be the physiological effect upon a marine organism which in its daily or seasonal wanderings may undergo changes of pressure to the amount of several atmospheres? One of the most noteworthy qualities of marine organisms is their capacity for rapid adaptation to great differences in pressure. To take only one conspicuous example, how does the whale escape the "caisson disease" when it "sounds" to pass in a few minutes through ranges of pressure that would completely wreck a human system even if it were allowed an almost indefinite period for the transition?

The whale, according to the best records, may dive rapidly to a depth of about four fifths of a mile, but not all marine animals are so adaptable. As Dr. Herdman has said, "If deep sea fishes accidentally get out of their accustomed depth and pressure, the expansion of air in their swim-bladders renders them so buoyant that they continue to tumble upwards to the surface, helpless, and eventually killed by the distention of their bodies and the disorganization of their tissues due to the diminished pressure. They die a violent death from falling upwards."[5]

Viscosity

Viscosity of sea water varies with the temperature, being nearly doubled by a fall of 20° C., although the change in viscosity is not precisely parallel with the change in temperature but increases

[5] Herdman, 1923, p. 161.

much more rapidly in the lower range. In consequence of the relation between viscosity and temperature, an object may sink much more rapidly at the surface than in the colder waters below. But any object will continue to sink if its specific gravity is higher than that of sea water at zero degrees. The old idea that sinking ships are arrested in their fall at some level of intermediate depth is, of course, without foundation. A wooden ship would indeed attain a greater sinking velocity as the pressure reduced its displacement by squeezing out the air from the wood cells. Contrary to what might be surmised, pressure does not materially effect viscosity. "The viscosity of pure water is even somewhat reduced by high pressure at temperatures below 32° C."[6]

The viscosity of the medium offers two of the marked contrasts between life in the water and life in the atmosphere. As any swimmer or any designer of automotive craft well knows, it requires a very much greater expenditure of energy to propel a body through water than it does to drive it through the atmosphere. One might suppose, then, that aquatic animals were necessarily slow of movement as compared with terrestrial animals, but again we find such adaptations of form and locomotive power that the speed of the swiftest animals of the sea, such as the bonitos and related fishes, and even bulky animals like porpoises and the larger whales, are capable of velocities of movement that compare well with (without perhaps equalling) those of the swiftest of terrestrial or aerial animals. There are, however, comparatively few marine animals with rates of locomotion comparable to the myriads of swift flying insects on land.

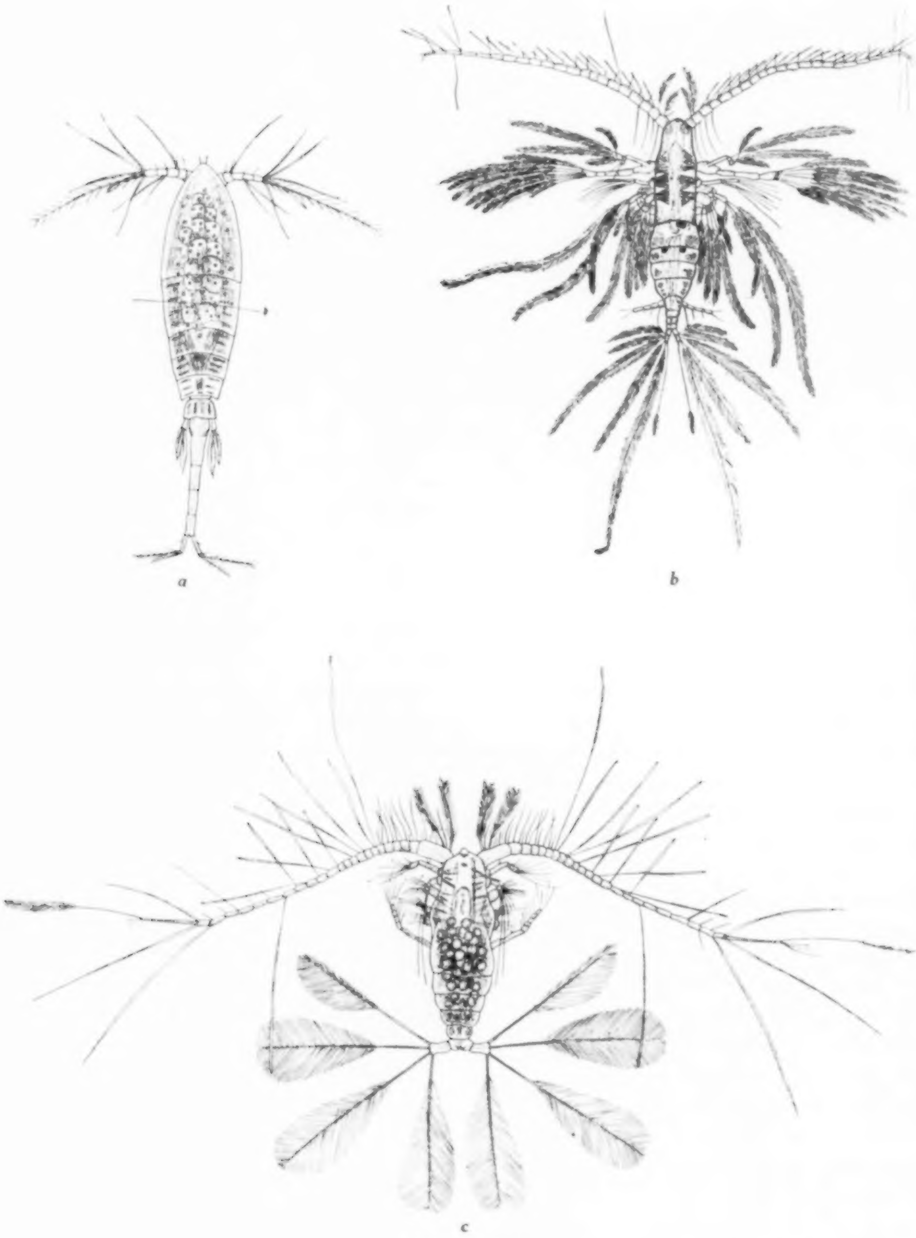
The viscosity of sea water has a further significance to organic life in water in that it retards sinking: but sinking velocity is also a function of form. Because of the inverse correlation of viscosity with temperature the viscosity of water, unlike its salinity, varies materially with the season. A peculiar phenomenon that has engaged the attention of many students of the drifting life of sea and fresh waters is the seasonal change of form manifested by some short-lived plants and animals. The change occurs not in the individual from time to time, but in successive generations; thus at any given time the animals (or the plants) may be quite different in appearance from their ancestors or from their descendants living within the same year but at other seasons. There seems clearly to be a variable adaptation between form and viscosity, but it is not so evident whether the change in form is actually induced by the changing viscosity or by changing temperature or by other conditions that vary concomitantly with temperature.

Density

The density of specific gravity of water is correlated with its salinity and is a measure of the effective weight of animals or plants in the sea. The specific gravity of sea water, of salinity of 35 parts per 1,000, is about 1.02813 at 0° C., but it is greater at lower temperatures and less at higher, and slightly greater under high pressure ($1\frac{3}{4}$ per cent. greater at 400 atmospheres—Murray and Hjort).

The protoplasm of marine animals is not greatly different from those of terrestrial animals, but the former live in a medium of approximately the same specific gravity as the living parts of their bodies, while the latter are surrounded by a medium of far less density. The support of the body against the pull of gravitation presents a problem to the terrestrial animal that must be met by adaptation in form, appendages, skeleton and muscles. This problem is less acutely felt by aquatic animals in fresh water, and much less so by those of marine habit. Even when on occasion the problem of support is not successfully met, the fall

[6] Krogh, 1934a, p. 431.



a b c

COPEPODS
(a) *Lubbockia squillimana*
(b) *Augaptilus filigerus*
(c) *Calocalanus pavo* (ALL AFTER GIESBRECHT).
IN "B" AND "C" ARE SEEN THE EXTREME DEVELOPMENT OF PLUMOSE SETAE AS SO-CALLED "FLOTATION PROCESSES."

of an animal on the land is a much more violent occurrence than the fall of an animal in the water. In the plant world as well, the differences in form and structure of terrestrial and marine plants are probably related in very large measure to the differences in density of the respective media in which they have their being.

Doubtless all marine animals and most marine plants are somewhat heavier than the surrounding media except as they have special buoyancy organs. But any one who has witnessed the explosion of dynamite in the water knows that some of the dead bodies rise to the surface, while others sink to the bottom. The problem for non-benthonic aquatic animals (those not living on the bottom) generally is that of keeping above the bottom rather than that of staying beneath the surface; falling to the bottom, it may be understood, is a serious matter, when the bottom is several miles removed and marked by conditions of pressure, temperature and darkness that may not be tolerable to organisms of the upper strata. Keeping within a zone of tolerable pressure represents for animals in the sea a problem to which there is nothing comparable for animals on land—the problem of falling neither downward nor upward to levels of extremely different conditions of pressure. Gas bladders, accumulations of fat or oil droplets contribute to buoyancy, while in both animals and plants notable extensions of the body surface, the so-called "flotation processes" offer resistance to sinking or serve as keels and rudders to facilitate movement in a horizontal or upward direction.

In this connection, as in others, reference may be made to the minute size of the vast majority of organisms of the sea, a condition that seems not to prevail to the same degree with land and fresh-water organisms. Doubtless, also a great number of small organisms quickly disintegrate after death into still smaller particles. Rate of sinking is a function both of weight and of the frictional resistance to movement through the water, and friction is a function both of the viscosity of the medium and of the surface area in contact with the medium.[7] The more viscous the medium and the greater the surface in proportion to mass, the slower the rate of falling. It is a well-known law that the smaller the object the greater is the surface relative to volume. As Krogh (1934, p. 423) has expressed it, "the rate of sinking of the minute plankton organisms is so slow that they can remain in the upper strata of the water for the length of their natural lives." But this does not answer the problem, for, unless the rate of sinking were zero, each succeeding generation would begin falling where the preceding generation had left off; so that after a few generations the bottom would be reached by all and the upper strata would have become entirely depopulated.

The rate of sinking can be zero only if the viscosity were infinitely great—that is to say, if the ocean were solid, which it is not; or if the ratio of surface to volume were infinitely great, which is impossible; or finally, if the organisms were of like weight with the water in which they live. Should the last condition prevail, there would be no need to invoke either viscosity of the medium or size and form of the organism as factors

7 By Stokes' law the rate of sinking is inversely proportional to the viscosity but directly proportional to the difference in specific gravity between the body and the medium. Sinking rate also depends upon size, varying with the square of the radius, and upon form. Stokes' law holds only for a small sphere, whereas the bodies of plankton organisms, which are generally of more or less irregular form, offer a special resistance derived from the increased area exposed to the medium. As the dead body sinks there is also the possibility of its taking up salts to bring its specific gravity nearer to that of the medium and thus to reduce its sinking velocity. There enters in also the influence of "eddy viscosity"—arising from conditions too complex for present discussion.

of retardation, since there would be no tendency to sink—nothing to be retarded. We might, however, assume that sinking at a very slow rate does occur, but that either some compensatory capacity for upward movement was inherent in the smallest organisms or that upward currents in the water lifted the organisms as much as they sank. The mechanics of flotation of non-motile or weakly motile organisms is not a fully solved problem. The phenomena of viscosity to be encountered are by no means so simple as might at first be thought. The sea is not static: there are movements of animals, of plants, even if only sinking movements, with accompanying disturbances of smaller or greater masses of water. Anywhere, too, there may be drifts or currents as yet little known, but producing correlative viscosity effects which can now be imperfectly analyzed by the most expert mathematician.

ATTACHING THE WATER BOTTLE TO THE HYDROGRAPHIC CABLE ON THE "CARNEGIE"

COURTESY OF THE CARNEGIE INSTITUTION OF WASHINGTON.

The contrast in density of sea water and fresh water is illustrated by the fact that many marine fishes have eggs that float at the surface, while all eggs of fresh-water fishes sink to the bottom, or are "demersal." Floating eggs are almost unknown in fresh water except among amphibia and some cladocera, occasionally, and a very few insects.

As a final word in this brief consideration of the subject of specific gravity, it may be remarked that the dead bodies of marine animals and plants must generally sink to the bottom except as they are devoured by scavengers or become dissolved in the water in the course of their long descent. Since sinking velocity varies directly with the size of the body, the smaller animals and plants are the more likely to be dissolved or to be devoured and later to reappear in part in new forms as soluble metabolic wastes of the "consumer." Bodies of larger organisms, sinking much more rapidly and dissolving more slowly, have the greater relative chance of reaching the bottom. Nevertheless we shall see later that the skeletons of myriads of minute plants and animals make up a large part of the deposits on the floor of the ocean. The remains of many large animals too are found at greater depths. Speaking of whales, Krogh (1934a, p. 433) says: "A sinking velocity of 100 m. per hour will bring a body to the bottom in most places in less than two days. At one station in the Southern Pacific the Challenger got up in the trawl from the red clay bottom at 4,300 m. (over 2½ miles) several thousand sharks teeth and not less than fifty ear bones of whales but of course it is not known how many thousands of years this accumulation required."

Penetration of Sunlight

The sun is the ultimate source of all the energies of plants and animals, but the greater part of the inhabited region of the earth is always in utter darkness. Even in the illuminated parts of the biosphere, light is perhaps the most variable of all conditions of the environment, for each day the light may fluctuate from the full daylight of noon to the darkness of midnight (Russell, 1936). The penetration of light into natural waters is significant in its physical relations as the different spectral components of daylight are differentially absorbed by the water and absorbed or scattered by dissolved and suspended substances, living or dead, and also as the temperature of the water is affected. Light is most significant biologically, as its intensity and quality affect photosynthesis and the formation of basic organic foods, including vitamins, as they influence the movements of photosynthetic organisms or of those that prey upon them, or as they have stimulative or lethal effects upon organisms brought into the upper strata.

The red component of sunlight is all absorbed, it is said, in the upper 500 meters (1,500 feet), while the rays of shorter wave-length, in the blue-violet end of the spectrum, may penetrate much deeper, to somewhere below 1,000 meters (3,300 feet).[8] It must not be imagined, however, that, practically speaking, absorption is uniformly or regularly proportionate to wave-length. Ultra-violet rays, or those just beyond the limit of visibility on the short-wave end, scarcely enter sea water at all. There are, moreover, considerable differences in the absorption of the several components of visible sunlight in different regions. Thus Oster and Clarke say that green and blue penetrate equally well in the Gulf of Maine (violet less well), but that blue goes deepest in the transparent water of the Sargasso Sea. Always the sea water is least transparent to red.

EMPTYING WATER BOTTLES OF SAMPLES TAKEN AT VARIOUS DEPTHS

COURTESY OF THE CARNEGIE INSTITUTION OF WASHINGTON.

[8] Hjort, from his own experiments, says that light penetrates to a depth of 1,000 meters (3,280 feet), but not to 1,700 meters. Beebe, on one of his descents in the bathosphere near the Bermudas, found light still visible to the eye at 1,900 feet (579 meters), but not the faintest hint of illumination at 2,000 feet. He adds (1935): "A problem of color not yet explained is that from 200 feet down, through the spectroscope, the blue is gradually replaced by violet, until at a depth of 400 feet the latter color is dominant. Yet, to the eye, at no time of the descent is there any trace of violet or lavender, only the strongest of blues, appearing brilliant long after it has lost all power for actually seeing anything in the bathysphere."

THE MONACO MUSEUM OF OCEANOGRAPHY
FROM HERDMAN.

Matter in suspension has much to do with absorption and scattering of light rays and thus with the visible color of the water. The short blue and violet rays are most effectively scattered by suspended particles, and, with the red and yellow wave-lengths quickly absorbed (converted into heat), green is left as the apparent color of the water where suspended matter is abundant. The less the numbers of solids or the more barren the water, the more regularly are the light rays absorbed in inverse proportion to wave-lengths and consequently the bluer the water.

The photic zone has been said to be the upper 1,000 meters (500 fathoms) in the clearer waters of the open ocean, but it is much less near land in higher latitudes. Indeed, the more conservative writers place the lower limit of photosynthetic activity at 200 meters or less. We may feel reasonably sure that photosynthetic plants can not live much below 1,000 meters, and doubtless few, if any, live at such a depth. Nevertheless, the green algae, Halosphaera, is reported to have been found by the plankton expedition at a greater depth. Minute plankton plants may on occasion fall slowly into the darker depths where conditions will not permit their continued growth and reproduction, but where they may continue to exist until devoured by the small plankton animals or lost by death and dissolution.

Except within the tropics the sun's rays strike the surface at an angle even at mid-day on the summer solstice; at all other times of the day, everywhere, the angles of incidence of the rays are such that a substantial proportion of the total sunlight must be reflected from the surface during the morning and afternoon hours. Harvey says that even in pure water about half the energy (light plus) is absorbed in the first meter and about 20 per cent. more in the second. Shelford and Gail (1922) tell us that even in the middle of the day, between 10 A.M. and 2 P.M., about a fourth of the sunlight falling on the water's surface in Puget Sound is reflected and that the light that penetrates is absorbed so rapidly as to be reduced by a fifth at a depth of one meter. Only 8 to 10 per cent. of the shorter wave-lengths entering the surface reach a depth of 10 meters. These data apply to conditions in calm weather; in rough weather 60 or 70 per cent. or even more may be blocked at the surface.

The length of the period of daylight is not the same beneath the surface as above it. Another observer has said that at a particular place, when the day at 20 meters was 11 hours long, at 30 meters it was 5 hours and at 40 meters but 15 minutes. The hours of effective daylight are, therefore, less below the surface of the water than above it and the duration of daylight must be the shorter the greater the depth.

The refractive power of water, or its capacity to bend light rays toward the vertical is to some extent a compensating feature permitting the rays that do enter to reach a greater depth. It may be noted, too, that much of the light that strikes the surface comes, not in direct passage from the sun, but by reflection from the sky. It would seem, nevertheless, that the maximum possible utiliza-

tion of sunlight and photosynthesis could not be as great in water as on land.

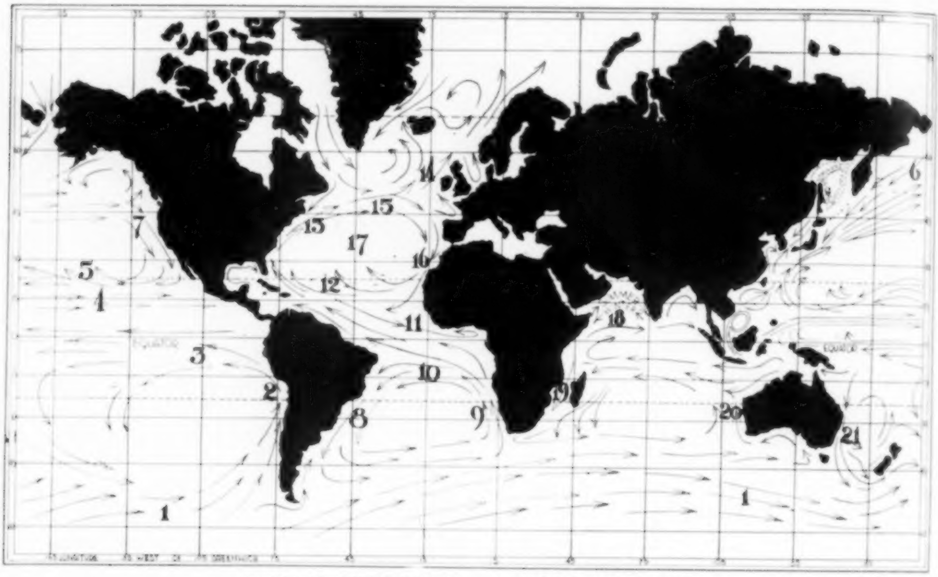
It must be kept in mind that, regardless of the depth of the sea, the total available sunlight in a given latitude and under given atmospheric conditions is a function, not of the volume of the body of water or the size of the body of the plant, but, rather, in each case, of the area of exposure. The amount of sunlight available for the production of organic material by plants is not, then, beyond certain limits, affected by the depth of the sea. To what extent other conditions than the availability of sunlight place a limit to its utilization on land or in water, may not be fully known, but the facts cited suggest the possibility that productivity as based on photosynthesis is at best restricted in the sea as compared with a corresponding area of land; and such a surmise would be equally applicable to bodies of fresh water. Animal life as a whole can not transcend or even equal their supply of vegetable food, but the animals in any one place are not always restricted to the plant food produced in that particular place. Nevertheless, in view of the disproportion of land and oceanic areas, the contribution of vegetable matter from the land to the sea must be relatively insignificant for the oceans as a whole, although, no doubt, of considerable importance to a narrow zone of coastal waters. In fresh water, on the other hand, the disproportion is quite the other way and the contribution of land vegetation to the basic food supply of animals in small lakes and streams may be relatively very considerable.

We need not, however, permit the logic of the stated facts to lead us to final or dogmatic conclusion. We may not have all the facts. Besides confessing ignorance as to what conditions, other than the physical availability of sunlight, affect the efficiency of plants in its utilization, we must face the special condition of the plant life of the sea: the bulk of the photosynthetic agents in the ocean is composed of an extraordinarily large number of exceedingly minute plants; protophytes whose dimensions are measured in a few thousandths of a millimeter. How, then, the enormous aggregate surface exposure of the marine phytoplanktons affects the total photosynthetic effect and the productiveness of the oceans as a whole is not a question to be lightly answered.

OCEANIC CURRENTS AND DRIFTS

The movements of water in the sea, apart from the lunar tides which involve only relatively small and local surface shifts of water, and the sun tides which, to some extent, reinforce or oppose the lunar tides, are governed by the winds, by influences associated with the rotation of the earth and by evaporation and its effect on salinity and specific gravity. In general, the great currents flow clockwise in the northern hemisphere and counter-clockwise in the southern. Principal of these are the east-west equatorial currents in the Atlantic and Pacific Oceans, the northeastward flowing "Gulf Stream"[9] in the western North Atlantic, the great Japan Current (Kuro-Siwa—"black tide") of the western North Pacific, and the Peru or Humboldt Current of the eastern South Pacific. The major currents of the sea are actually powerful streams obvious to the senses. The Humboldt Current lends itself particularly well to observation, since there occur in its path islands near which one may anchor and, even there where the flow must be retarded by the obstruction, one may both see and hear the flow of water, moving in one direction as ceaselessly and as rapidly as the streaming of a great river. To the great stream

[9] Perhaps incorrectly so called, since its waters are now presumed to come almost exclusively from the Caribbean following a direct route from the Yucatan Channel to the Straits of Florida along the north coast of Cuba.



OCEAN CURRENTS. (AFTER SCHOTT)

1. Antarctic West Wind Drift
2. Peru Current (Humboldt)
3. South Equatorial Current
4. Counter Equatorial Current
5. North Equatorial Current
6. Kuro Siwa
7. California Current
8. Brazil Current
9. Benguela Current
10. South Equatorial Current
11. Guinea Current
12. North Equatorial Current
13. Gulf Stream
14. North Atlantic Drift
15. West Wind Drift
16. Canaries Drift
17. Sargasso Sea
18. Monsoon Drift (Summer East, Winter West)
19. Mozambique Current
20. West Australian Current
21. East Australian Current

just mentioned we might add the Labrador Current, which flows southward following the eastern border of the Grand Banks and then turns outward flowing somewhat parallel to the Gulf Stream which has here a northeastward trend.[10] These great currents are relatively surface phenomena, but we might refer also to the more leisurely "drifts" of abyssal waters, such as that of the Antarctic waters that are presumed to flow northward across the equator and over the bottom of the North Pacific. The rate of flow at great depths has been estimated at about 1½ miles per day. In the Atlantic the main body of the deeper water seems to move in a southerly direction, with a yet deeper drift of Antarctic water flowing northward as far as 34°–40° North Latitude.

[10] Smith, Soule and Mosby, p. 170, 1937.

Great currents and drifts do not, by any means, tell the whole story of the dynamics of the sea. There are deep tidal waves of great amplitude that may influence the whole mass of water, and there are diverse turbulence phenomena that preclude analysis in simple language.

Slow upwelling movements are also known to occur along the western shores of North America, South America and Africa. The rate of upwelling along the coast of Southern California has been estimated by McEwen as of the order of about one meter per day—a slow rise, indeed, but fast enough to be, as we have already suggested, of great significance in restoring to circulation in the upper waters the dissolved materials that would otherwise be irretrievably lost in the abyss. The upwelling of cold abyssal

waters tends also to lower the temperature of coastal waters. Thus the coolness of the waters that bathe the coasts of California in the northern hemisphere and of Peru in the southern hemisphere is not due entirely to the surface currents flowing toward the equator from Arctic and Antarctic regions, respectively. Indeed, it is said that the waters of the western coast of North America actually become colder in places as they move southward, and surely the surface waters of the Humboldt Current are warmed but slightly as they flow along the coast of Peru for more than a thousand miles beneath the clear tropical sun.

Again, there are vertical movements arising from differentials in specific gravity. When evaporation has so concentrated the superficial waters as disproportionately to alter the specific gravity, the heavier concentrated waters must sink below to be replaced by more dilute and higher waters from beneath. Vertical movements from this cause are perhaps not very significant as suggested by our comment in a later paragraph. In higher latitudes the cooling of surface waters increases its weight so that wherever it overlies warmer and higher waters there must occur convection currents that cause an interchange of positions. There may, too, be other causes of vertical movements that are less well understood.

Were it not for some sort of mixing apparatus, the sea water would have diverse chemical composition and very different concentrations in various parts

SUNSET ON THE PACIFIC OCEAN

TAKEN FROM THE "CARNEGIE." COURTESY OF THE CARNEGIE INSTITUTION OF WASHINGTON (C2409).

of the world; but we have seen that this is not the case. A mixing apparatus on a grand scale is formed by the currents and drifts, the upwellings and convection currents and the oscillations and turbulence phenomena to which allusions have been made. The sea is not a static body, but everywhere a dynamic one.

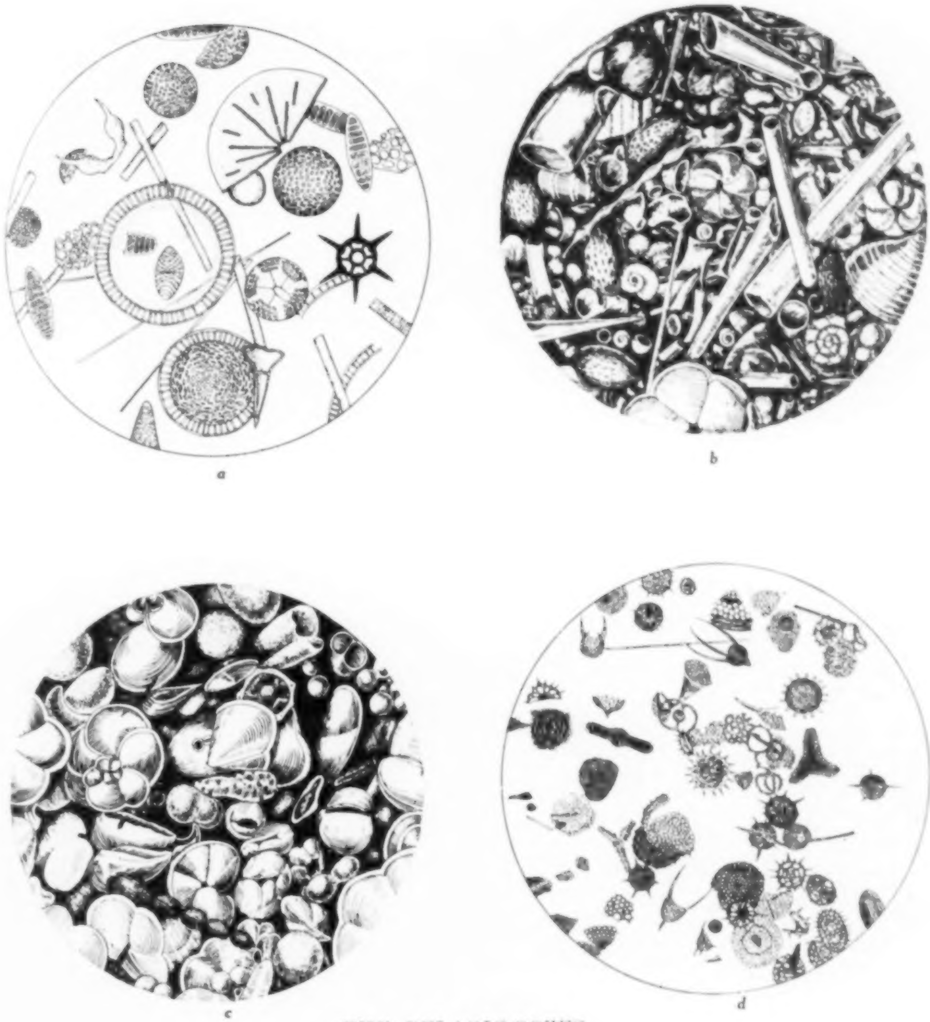
THE BOTTOM

The bottom is covered by deposits of various kinds which may be considered in three chief groups: (1) *Terrigenous*, about two thirds quartz and other mineral matter washed down from the land and being some 68 per cent. silica; (2) *Neritic*, consisting of materials from the land mixed with organic substances formed in the shallow coastal waters, such as the remains of mollusks, crustacea, echinoderms, worm tubes, etc.; and (3) *Pelagic*, comprising materials originating almost exclusively in the sea or coming from the atmosphere or interplanetary spaces. Terrigenous and Neritic deposits are, of course, found chiefly on the Continental Shelf. The Terrigenous deposits are the shallow water sands and muds, in which quartz grains constitute a prominent part, and the deeper red, blue and green muds, with colors due to predominance of different mineral substances, such as oxides of iron and manganese and glauconite (silicates or iron and potassium); with the Terrigenous deposits may also be listed the volcanic muds and coral sands and muds of certain regions.

The Pelagic deposits comprise four chief "oozes" of organic origin and "Red Clay." *Diatomaceous Ooze* is found almost exclusively in cold regions of the

THE SEA IS NOT ALWAYS SMOOTH

THE "CARNEGIE" MEETS HEAVY SEAS IN THE SOUTHERN OCEAN. (C1863) COURTESY OF THE CARNEGIE INSTITUTION OF WASHINGTON.



THE PELAGIC OOZES
(a) DIATOM OOZE (FROM STEUER AFTER CHUN)
(b) PTEROPOD OOZE (AFTER MURRAY AND HJORT)
(c) GLOBIGERINA OOZE (AFTER MURRAY)
(d) RADIOLARIAN OOZE (FROM STEUER AFTER KRÜMMEL)

Antarctic and of the southern and far northern Pacific at 600–2,000 fathoms. The siliceous shells of diatoms are found in such deposits in extraordinary numbers. The calcareous *Pteropod Ooze*, comprising the shells of the pelagic mollusks (pteropods and heteropods) mixed with shells of Globigerina and other materials, occur principally in tropical regions at less than 1,000 fathoms. Two kinds of pelagic Protozoa contribute materially to the floor of the ocean. About 40 per cent. of the floor of the north Atlantic, and perhaps one third of the total area of all sea bottom, is covered by *Globigerina Ooze*, composed in considerable part of the calcareous shells of the foraminiferan *Globigerina bulloides*, mixed with coccoliths, to be mentioned later; this deposit is about 65 per cent. calcareous mat-

ter and is found at 1,000–2,500 fathoms. Although it was once supposed that Globigerina Ooze was the basis of chalk deposits, it is now believed that the chalk was formed in shallow seas and that such deposits do not, therefore, represent old deep sea bottoms.[11] In contrast to the calcareous ooze just mentioned, is the siliceous *Radiolarian Ooze*, consisting of a foundation of red clay in which are mixed the remains of Radiolarian shells; it occurs at 2,500–5,000 fathoms in isolated areas of the tropical Pacific and Indian Oceans. Finally, the *Red Clay*, constituting more than half of the floor of the Pacific and about one third of the combined area of the floor of all the seas, is composed of silicates of aluminum, iron and manganese, volcanic dust, interstellar dust and, in small part, of the residue of organisms. This Red Clay of the sea bottom is not to be confused with the red clay of the land. The color of the submarine Red Clay is believed to be due to oxides of iron and manganese derived from volcanic dust. It accumulates with exceeding slowness; Sir John Murray has estimated that there has been an increment of about one foot since Tertiary times! There is no rock in the geological series that corresponds to the Red Clay of the ocean floor, and this leads us to believe in the relative permanence of the deeper parts of the seas; no present area of land seems to comprise what has ever been the red clay areas of sea bottoms.

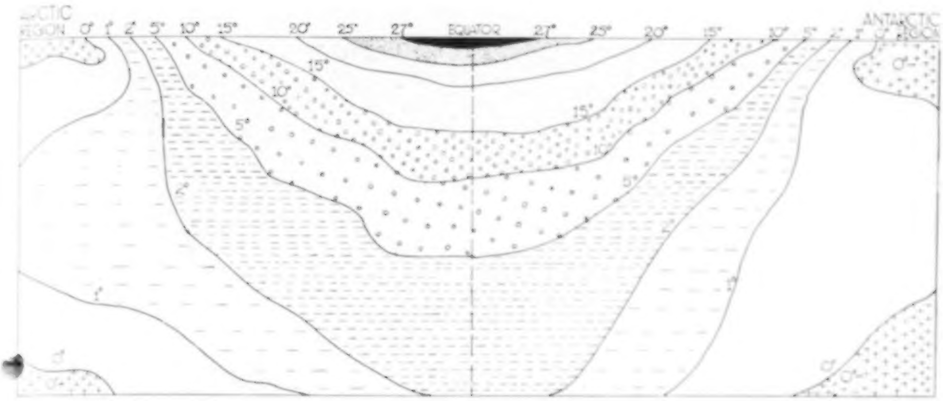
TEMPERATURE

The temperature of the surface water in the ocean varies with seasons and with latitude, but the temperature in any given latitude is not uniform from east to west. Because of the currents previously alluded to, which convey great masses of equatorial water toward the poles and others that return waters from Arctic and Antarctic regions toward the tropics, and, in part, because also of sinking and upwelling movements of the water in different regions, the seas are warmest in the eastern sides in the northern hemisphere and in the western sides in the southern hemisphere. At the worst, the seasonal variations in temperature are relatively small as compared with those that prevail on land at low altitude in temperate and sub-polar regions and as compared with those of most fresh waters in the same regions. Indeed, beyond a depth of about 200 meters seasonal variations do not occur at all. Differences between summer and winter temperatures of the Atlantic Ocean are least in polar and tropical regions, greatest in the northern temperate zone (10°–50° F.) (5.5°–28° C.). Variations with latitude are notably modified by ocean currents; so that, while comparatively warm water occurs in the course of the Gulf Stream far in the northern Atlantic, surprisingly cold water is encountered in the path of the Humboldt Current very close to the equator in the eastern part of the Pacific Ocean. The drift of icebergs also has an observable effect on the temperature of the North Atlantic, effects that vary with the year and with the shifts of currents.

Unlike fresh water, sea water becomes heavier as it is cooled until its freezing point is reached,[12] so that the limitation of 4° C. for temperatures at the bottom of lakes does not apply in the sea and bottom temperatures of $-1°$ or lower may occur in polar currents; but, although the freezing point of sea water ($-1.9°$ for water with salinity of 3.5 per cent.) is substantially lowered under high pressure, bot-

[11] Bigelow (1931, p. 35) refers to Globigerina Ooze as reported to be accumulating over submarine telegraph cables at the apparent rate of a tenth of an inch a year or a fathom in 720 years, but comments that the sea floor generally over all the vast area occupied by the Globigerina Ooze is certainly not building up at such a rate.

[12] This applies to water with a salinity of 24.7 per M. or higher.



SCHEMATIC REPRESENTATION OF DISTRIBUTION OF TEMPERATURES BY DEPTH AND LATITUDE

SHOWING POSSIBLE CONTINUITY OF ZONES OF LOW TEMPERATURES THROUGH ALL LATITUDES. DEPTH SCALE GREATLY EXAGGERATED RELATIVE TO LATITUDE SCALE. (SUGGESTED BY CHART OF CHUN FOR A RESTRICTED REGION.)

The sketch is crude and makes no pretence of offering a reliable picture of the actual conditions of temperature in any latitude. For a more informative and accurate but more complex representation of the distribution of temperatures in the deeper waters of the Atlantic, see the charts of Georg Wüst in one of the "Meteor Reports:" Schichtung und Zirkulation des Atlantic Ozeans, erste Lieferung: Das Bodenwasser und die Gliederung der Atlantischen Tiefsee: Berlin and Leipzig, 1933.

tom temperatures below the freezing point seem to be very rare; indeed, the temperature of abyssal waters is usually a little above zero, owing no doubt in great part to what Helland-Hansen has called "adiabatic warming"—warming resulting from the effect of pressure. In the North Atlantic generally the bottom temperature is around 2° C. The bottom water is very cold in the tropics as well as in polar regions. "Over 4/5 of the ocean floor exceeds one mile in depth and has a temperature colder than 3° C."[13] The barriers of temperature and pressure that exist between the bottom and the surface at the equator (separated by a distance of 4 or 5 miles) are much more effective than those that exist between two points on the bottom 10,000 miles apart.

The source of heat in the sea is the surface where heat is derived by absorption of the rays from the sun and by radiation from heated air. The amount that can be absorbed is a function of the surface area and also of the heat coefficient of water, which is relatively low. On the other hand, there must occur a great loss of heat through evaporation. The distribution of heat in the sea is affected, in part by the currents that move between warmer and colder parts of the earth, in part by vertical currents brought about by a variety of causes; upwelling movements on the west coasts of the continents have previously been referred to. Evaporation, of course, tends to increase the density and weight of surface water and might be expected to cause it to sink, but vertical movements from this cause are believed to be relatively insignificant—because, where evaporation is considerable, as in warmer regions, its effect in raising specific gravity is more than counterbalanced by the increase in density resulting from the warming of the surface water. The lower salinity of surface water over the Continental Shelf, where the run-off from land is felt, and the higher temperature of surface waters over the seas generally both tend to keep top water on top. Nevertheless, "overturn" occurs in high latitudes, especially in or at the end of winter, whenever the

[13] ZoBell, 1934.

surface-cooled waters become colder and heavier than those beneath them; but the overturn affects, perhaps, only the waters above the thermocline or zone of most rapid change of temperature.

Temperature apparently exerts in many ways an influence on the chemical activities in protoplasm that underlie growth, form and multiplication. Rate of photosynthesis and rates of biological activities in general may be approximately doubled by a rise of 10° C. Temperature governs, to some extent, the distribution of animals and plants and, where a particular species has a range extending through low and high latitudes, its form or the character of its shell may differ with the latitude. Again, as was mentioned in connection with the consideration of density, the form of an animal or plant in a given region may be notably different in summer from that which it has in winter. It is not, however, easily determined whether the differences that appear to go with temperature are governed actually by temperature or by other environmental conditions which are associated causally or accidentally with temperature. In many instances, and perhaps as a general rule, the size that an animal attains is greater when it is reared at a lower temperature.

Gran says: "Temperature, more perhaps than any other factor, determines the growth and decrease of the various species and the character of the communities dominating the plankton. But some species are adapted even to the most extreme temperatures found in the sea and a rich growth can take place as well at the lowest (–1.5°) as at the highest temperatures observed."[14] "Temperature," says Martin (1922, p. 457), "is less directly important in the sea than on land since there is no great danger of injurious extremes being reached. Indirectly, its importance lies in the fact that carbon dioxide is much more soluble in cold water than in warm, and it is probably this, rather than the direct influence of temperature, which accounts for the fact that the most luxuriant development of plant life is in the colder waters of the earth."[15] Allen (1934, p. 175), however, questions the certainty of a generally greater productivity of plankton in high as compared with low latitudes.

14 Gran, 1932, p. 348.

15 Martin, 1922, p. 457.

(To be concluded)

A STUDY IN PREDATORY RELATIONSHIP WITH PARTICULAR REFERENCE TO THE WOLF

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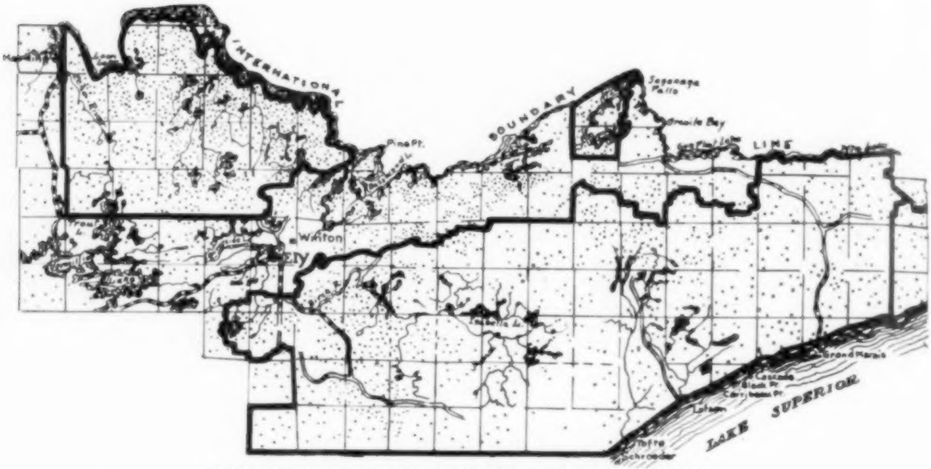
DURING the past quarter of a century, the American people have heard much in regard to the conservation of animal life, but stress has been largely placed on the saving and protection of herbivores at the expense of predatory forms. The predators, those animals which live perforce upon the herbivores, have not as a rule come under the plan of conservation as outlined, and in many areas attempts have been made to eliminate them entirely with total disregard for the influence these forms might have upon the balance of life in the communities of which they are a part.

Game refuges have often been administered as herbivore sanctuaries, until today there are comparatively few areas in which the original animal population can be said to exist under primitive conditions. The tendency has been one of extermination, particularly for the larger

TYPICAL PANORAMA OF THE GAME COUNTRY OF THE SUPERIOR NATIONAL FOREST.

DARK AREAS, LARGELY RED PINE (*Pinus resinosa*), WHITE PINE (*Pinus strobus*), JACK PINE (*Pinus banksiana*), SPRUCE (*Picea canadensis* AND *P. mariana*), AND BALSAM (*Abies balsamea*). LIGHTER AREAS IN THE FAR DISTANCE AND CENTER, ASPEN (*Populus tremuloides*) AND CANOE BIRCH (*Betula papyrifera*). DEAD BIRCHES ALONG THE SHORE OF THE LAKE, DUE TO RAISING OF WATER BY BEAVER DAM AT OUTLET. TAKEN FROM ENSIGN LOOKOUT, JULY, 1932.



DISTRIBUTION OF WOLVES AND COYOTES.
DENSITY OF DOTS INDICATES RELATIVE ABUNDANCE.

predators, the wolf, the coyote and the mountain lion, and little scientific investigation has been carried on to determine the exact status of these forms in relation to the herbivores upon which they prey.

The extermination of predators is no longer a strictly economic problem, for other factors have entered in, factors of scientific, recreational and esthetic value. With the fast-growing appreciation of the true meaning of wilderness, we are beginning to question the idea of the total elimination of predators, realizing that, after all, lions, wolves and coyotes may be an exceedingly vital part of a primitive community, a part which once removed would disturb the delicate ecological adjustment of dependent types and take from a country a charm and uniqueness which is irreplaceable. To go into a region where the large carnivores are gone, to see hoofed game with its natural alertness lacking, to know above all that the primitive population has been tampered with, is like traveling through a cultivated estate. Wilderness in all its forms is what the true observer wants to see and with this realization dawns a new appreciation of carnivores and the rôle they play.

The fact that in 1928, out of tens of thousands of carnivores killed in the West, there were only eleven grey wolves recorded, that in the state of Wyoming a few years ago only five wolves were reported at large, points definitely toward ultimate extinction in those areas. In 1926 the Biological Survey reported no wolves in Arizona, and recent reports from other regions indicate a similar scarcity. In the Middle West and East, only occasionally, is a specimen recorded. In the hinterlands of Canada and in the fringe of wilderness along the northern borders of the lake states are all the wolves that are left, and at the present rate of depletion, the area encompassed by the Superior National Forest in northeastern Minnesota will soon include most of the remaining animals of the species in the United States.

Any one who has made a study of the life histories of the larger predators knows that the accusations against them are not entirely without grounds. On the other hand, it is not hard to see that many indictments are made without sufficient proof to substantiate them. It is therefore the purpose of this paper to bring out a few outstanding facts regarding the life habits of one of the largest and most maligned of the predators, the timber

wolf of the north (*Canis nubilus* Say), in the hope that some day accumulating evidence may grant it the protection and sanctuary which other forms of life now enjoy. I shall also contend that a large wilderness area may harbor a carnivore population without danger of annihilation to hoofed game and that the constant presence of such large animals of prey as the timber wolf may actually prove of benefit to the herd.

All investigations have been carried on within the boundaries of the Superior National Forest, a comparatively primitive area, where the deer (*Odocoileus virginianus borealis* Miller), and the moose, (*Alces americana americana* Clinton), are present in fairly large numbers. Although predatory animal control has been exercised for a number of years, it has been done in a rather haphazard fashion and with no great diminution of the species in question. Natural conditions prevail over much of the area, so that observations recorded should give a true picture of predatory relationships in an undisturbed situation. A great many observations are the result of a long time study not only by the author but others who are familiar with wilderness conditions. These are conclusions arrived at after many years of experience in the north, unfortunately not always from carefully kept notebooks, but rather in many cases as general conclusions based on personal deductions. This applies to a good many of the points made in the paper under discussion. The writer's experience in this particular region covers roughly the period from 1920 to the present. During this time he has covered thousands of miles, by canoe, on snowshoes, on foot and by airplane, and feels that he knows the country fairly well. The conclusions drawn are based on incidents and observations, which, had he kept a careful notebook, would be easy to cite, but like those of most other woodsmen, they are the sum total of experiences and general working

SCATTERED ASPEN (*POPULUS TREMULOIDES*)
AND JACK PINE (*Pinus banksiana*) ON THE NORTH BANK OF THE KAWISHOWA RIVER, A FAVORITE FEEDING GROUND FOR DEER IN THE EARLY SPRING. APRIL 1931.

BARREN BURNED OVER AREA NORTHWEST OF DEADMAN'S PORTAGE ON THE KAWISHOWA RIVER.

NOTE SPARSENESS OF VEGETATION IN FOREGROUND, SCATTERED CLUMPS OF ALDER (*Alnus incana*) AND HAZEL (*Corylus rostrata*), ALSO THE MUCH HEAVIER VEGETATION IN GULLIES AND RAVINES. THIS IS AN AREA OF DEER CONCENTRATION IN THE EARLY SPRING AND LATE FALL. AT TIME PICTURE WAS TAKEN, MARCH 1930, THERE WERE AT LEAST 20 DEER IN THE AREA SHOWN.

knowledge for which it is impossible to cite authority accurately. The best the writer can say is that they represent what he considers his most accurate judgment of the problem involved.

General Survey of the Superior Area[1]

The Superior National Forest lies in the northeast corner of Minnesota and is bounded on the north by a similar *region*, the Quetico Provincial Park of Ontario and on the south by the north shore of Lake Superior. Both areas, including approximately four million acres, are timber and game preserves, and inasmuch as the country is largely inaccessible, except by canoe in the summer and dog team in the winter, it is comparatively free from molestation. All population figures have been based on the approximately 2,500 square miles of wilderness south of the Canadian border.

The general topography is rough, rocky and well glaciated. The vegetation is largely second growth northern coniferous forest, interspersed by areas of the original white pine (*Pinus strobus*) and red pine (*Pinus resinosa*) climax. Fires have swept certain parts repeatedly and the resulting young growth of aspen and birch has been particularly favorable as feeding ground for deer and moose. Intersecting the entire region are thousands of rock-bound lakes and streams, all connected in a vast labyrinthian waterway. The general drainage is

[1] Based upon personal observations entirely, 1920 to 1936. Area figures from the U. S. Forest Service and State Conservation Department.

either to the north and west into the Lake of the Woods and Hudson's Bay, or south into Lake Superior. It is one of the few areas of its type still undeveloped and becomes therefore of great ecological importance. With the exception of the caribou (*Rangifer caribou* Gmelin), which migrated to the north forty years ago, together with the wolverine (*Gulo luscus* L.) and the pine marten (*Martes americana* Turton), there is little change in animal types since the days when the voyageurs of the Hudson's Bay Company traversed the waterways in quest of fur.

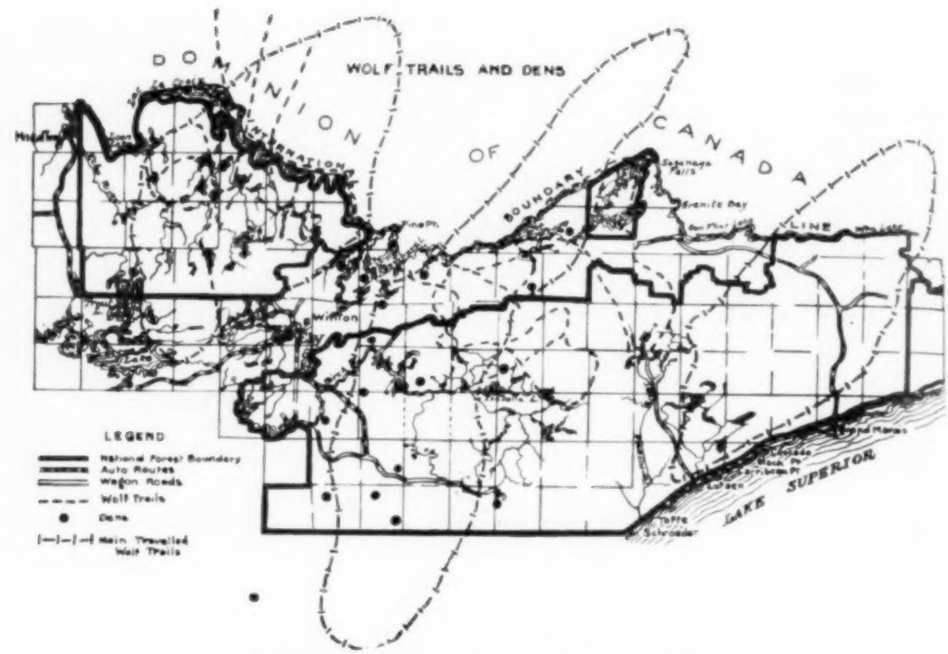
Survey of the Wolf Population[2]

It must be remembered that the wolf population is a shifting one and the very fact that the Quetico Provincial Park of Ontario lies immediately north with an open boundary of over a hundred miles in length, makes it very difficult to lay down any definite figures as to exact or permanent numbers. Wolves have runs of from twenty to a hundred miles in length, and shifting back and forth across the border, as is their wont, makes it often difficult to decide just where a certain pack belongs. Another factor which must be considered is their constant following of the deer herds from one area of big game concentration to another. Hence, the observations and conclusions given here have necessarily been arrived at over a period of years and every allowance for inaccuracy due to the above factors has been taken into consideration. However, though the figures must be

[2] Wolf populations were reported as follows: 1930, William F. Hanson, game warden, 350 wolves; 1931, Thomas Denley, forest ranger, 228 wolves; 1930, Superintendent John Jamieson, of Quetico Park, 62 wolves for the Quetico; 1929, Jack Linklater, Hudson's Bay trapper and warden, 250 wolves.

TYPICAL SPRUCE BOG HABITAT.

NOTE THE ISLANDS OF SPRUCE IN MIDDLE FOREGROUND, JACK PINE RIDGE AT RIGHT. VEGETATION IN FOREGROUND, ALDER, WILLOWS (*Salix sp.*), DWARF BIRCH (*Betula pumila*), AND HEATH PLANTS. A FAMOUS DEER TRAIL CROSSES THIS BOG. STONEY RIVER COUNTRY, NOV. 1932.



HUNTING ROUTES OF WOLF PACKS.

approximate, they are sufficiently correct to establish the contention of this paper.

My personal observations and those of government rangers, hunters and trappers, points to a present wolf population of about 250 animals or one to every ten square miles of the area under consideration. This figure is not uniform for the entire region and is entirely dependent upon the concentration of game. It can be said, however, that the number of wolves increases in direct proportion to the herbivore population.

In view of the above estimate, it may be interesting to compare the conclusions of Ernest Thompson Seton and Vernon Bailey. According to their figures, the original primitive wolf range on the continent was approximately 7,000,000 square miles. Over this territory were distributed about 2,000,000 animals or one to every three and one half square miles. The wolf population as late as 1908 was estimated at 200,000 for North America, of which only 2,000 were to be found in the West, their former stronghold. That was a quarter of a century ago, and inasmuch as killing has gone on apace since then, it is reasonable to assume that only a fraction of that number exists to-day. Of the 200,000 mentioned in 1908, half were relegated to the hinterlands of Canada or one to three square miles, and half to the United States or one to seven square miles of the remaining range. A recent estimate from Algonquin National Park of Ontario, east of the Quetico-Superior area, gives the wolf population as one to four square miles.

There are, unfortunately, no early records for the Superior Forest Area, but it is doubtful if the original population figures of one to three square miles would have held for this region. When we consider that the moose and caribou occupied the country prior to its logging some thirty to forty years ago and that they as species were not nearly as numerous as the deer of to-day, it is a safe con-

jecture that the wolf population was perhaps not higher than one to five square miles or twice the present estimate.

Hunting and Feeding Habits of the Wolf

The entire problem of predatory relationship is based upon the food habits of the carnivores concerned. This is the phase of life history which determines whether or not a species is an acceptable member of any society. Certainly, the most often voiced complaint against the timber wolf is that it is a killer of deer, and that there is a certain amount of truth to this contention stands without question.

The major portion of the food of the wolf[3] during the summer months is grouse, woodmice, meadow voles, fish, marmots, snakes, insects and some vegetation. In fact, almost anything that crawls, swims or flies may be included in its diet. During the winter months, when most of the small animals are in hibernation, the wolf is forced to feed almost entirely upon deer and the snowshoe rabbit (*Lepus americanus* Erxleben). The wolf is never a consistent and regular feeder and can go for long periods without food. When food is scarce, as it often is in the north, three or four meals a month will keep him from starvation.

Close students of wild life in the border country all agree that wolves kill comparatively few deer, and then only in the late winter and early spring periods. While there are instances of individual killers, both in the north and the west, who have slaughtered large numbers of deer, moose or elk during the course of a winter, it is no more true to say that these isolated instances are the normal feeding and killing habits of wolves as a species than it is to say that because a man runs amuck his behavior is an index

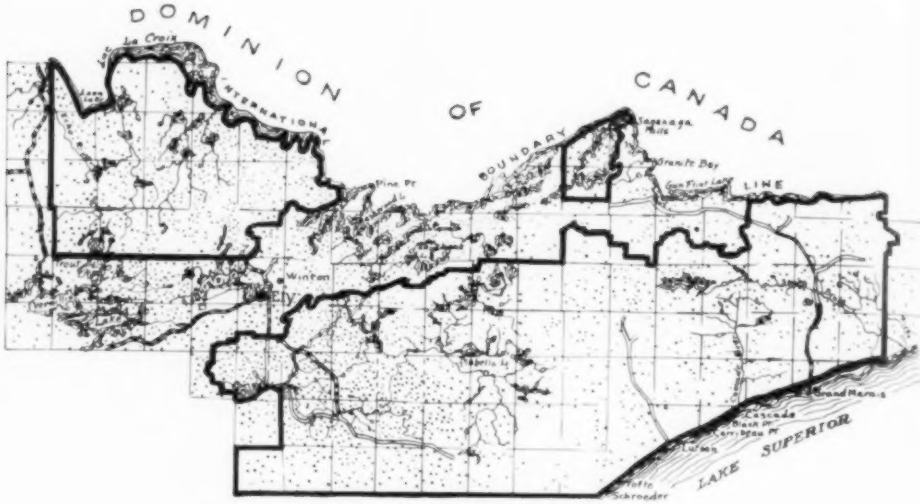
ABOVE: READING FROM LEFT TO RIGHT, SILVER FOX, RED FOX, TIMBER WOLF AND COYOTE, ALL POISONED IN WOODS LAKE AREA, FEBRUARY, 1927. BELOW: DEER CARCASS FOUND NEAR THE WEST SHORE OF SNOWBANK LAKE, MARCH, 1931. NOTE THE WELL-PICKED BONES.

for the rest of his kind. Like all omnivorous types, the wolf prefers variety in his diet and only takes the big game trails when driven to it by the scarcity of the normal food supply.

The actual hunting habits[4] of wolves are dependent upon the terrain and inasmuch as the Superior Area is such a heterogeneous mixture of widely diversified habitats, each having its own particular influence not only upon the game

[3] Food of the wolf is based upon personal observations. Stomach contents of wolves, 1929–1930 winter: 14 carcasses; reports from Jack Linklater, 1920–1930; Tom Denley, 1931.

[4] Hunting areas are based upon personal observations, 1920–1936; Jack Linklater, 1900–1930; Thomas Denley, 1900–1930; Charles Lainey, 1930; William Hanson, 1920–1930.



DISTRIBUTION OF DEER.
DENSITY OF DOTS INDICATES RELATIVE ABUNDANCE.

population but on the methods of hunting, it is imperative that we survey the region from this angle.

Virgin stands of pine shelter little game and are unimportant from the standpoint of hunting and food. There is only one exception to this type of habitat and that is the dense stands of Jack pine (*Pinus banksiana*) which deer and moose often frequent during winter storm periods. Such areas are literally criss-crossed with game trails, and wolves in their hunting follow them continually in an effort to drive their prey out into the open.

The greatest game producing areas are the mixed stands of aspen and birch which have grown up either after logging operations or fires. The bulk of the vegetation of the Superior Forest is of this type, interspersed with scattered white spruce, dense thickets of balsam and second growth white and red pine. Here is the ideal feeding ground for deer, for in a predominantly deciduous growth of this type there is always an abundance of herbaceous material, as well as shrubs and young saplings upon which they can browse. The rolling timbered ridges, swamps and swales, beaver flowages, brush-grown gullies and ravines not only furnish excellent cover and protection but food as well, and here is the maximum game population. The network of game trails traversing areas of this type are the logical starting points for the hunting activities of the large predators.

The open country which has been logged and burned time and again is of particular interest because of the dense growths of spruce, cedar, alder and willow in the creek bottoms and gulleys between the barren ridges. Deer, feeding in the open, always seek the bottom lands during part of the day, and it is here that the wolves make their most successful drives. During the late fall and early spring, the open ridges are important feeding grounds, as they remain free of snow longer than the timbered regions and become exposed considerably earlier than the valleys.

The great spruce bogs and swamps are of no great influence unless they happen to lie in between good feeding areas. Occasionally during heavy snows, both deer and moose yard up in such places for short periods, but food is never plentiful

enough so that they remain very long in one location. Cedar swamps, however, play a very important part in the winter feeding of big game animals. Deer especially congregate in such areas not only for the excellent protection they afford, but for the cedar twigs upon which they browse. Between late December and April when the snow is often very deep and ordinary food practically inaccessible, one can always find deer in such locations. In fact, during such periods, deer have been known to become so partial to this food that they preferred it to tame hay distributed by wardens of the Conservation Department.[5] Wolves on the hunt often attempt to drive such yarded animals out into the deep snow for slaughter but are seldom successful. In working such a ruse they are forced to exercise great caution, for once a wolf is caught in the well-trampled trails of the yard there is little chance to escape the sharp hoofs of its intended prey.

The many barren, meandering ridges of rock are of no significance from the standpoint of game, but they do play an important part in the technique of hunting. A cruising wolf will run along the crest of one of these open ridges, nose in the wind, keeping watch over the surrounding country. When he tires, he will often curl up to rest on some outstanding promontory where nothing will escape him. Packs have important passes and crossing places on these dividing ridges where they not only meet but leave their scent. It is from such elevations that leaders call the members of their packs together, and it is here that many hunts begin.

When the lakes and streams freeze over, they become at once a highway for all forms of wilderness life, and it is here that most of the kills are made. Usually wolves follow the shore from which the wind is coming, investigating at the same time any bays which might shelter game. When the wind informs them of game inland, they leave the lake shore immediately. On the rock ridges they stay close together, but in the valleys they spread out fan like, covering the ground systematically. The instant a deer is started, they try to force it back onto the smooth glare ice of the lake, where it will lose its footing and be easily dispatched. Often a deer will, in spite of their efforts, force its way back into the timber and then it becomes a test of speed and endurance. If the snow is not too deep or the crust too heavy, the deer have little to fear and can usually outdistance their pursuers. Occasionally, if conditions are right, a small pack will work the relay system of hunting and in some instances actually use the strategy of ambush. There are as many different ways of hunting and killing as there are situations which arise in the process. Wolves, like all carnivores, are adaptable and have a certain amount of inherent cunning which is brought into play to combat the natural obstacles which stand between them and their food. Pack leaders are those individuals which have demonstrated repeatedly their ability to provide their followers with game.

Perhaps the favorite hunting grounds for all wolves are the fringes of swamps. These alder-grown grassy margins are alive with mice, voles and rabbits, and can always be depended upon to furnish something in the way of food. Single wolves or pairs most often frequent such small game areas. Packs seldom include them in their foraging, as they are out for bigger game. Lake shores and the borders of creeks and brushy gullies come under this category. It can safely be said that outside of the movements of the packs themselves during the winter season, most of the actual hunting of the wolf family is done in such locations within easy range of their dens.

[5] Personal observations, 1936, Mud Creek Swamp, Twin Lakes Swamp. Byron Carlson, 1936, Mud Creek, Ely Buyck Road. State Game Warden.

Organization and Range of the Pack[6]

Packs vary in number from five to thirty, the smaller group being by far the most common. A pack of eighteen was seen on the Stoney River in 1918 (Denley) and one of twenty on Crooked Lake in 1922 (Linklater). Less than six is usually the case. These small packs, most often seen crossing the open lakes in midwinter, represent as a rule a pair of old wolves and their surviving pups. Wolves sometimes kill big game while hunting alone, but most of the actual killing is done either by the members of last season's family or, in the case of large packs, by several families which have banded together.

Such hunting units may travel from twenty to forty miles a day and are sometimes found as far apart as Knife and Crooked Lake, a distance of thirty miles, on consecutive days. Ordinarily, they have a beat which they cover every two or three weeks and a trapper who knows the route of a pack can bank on the possibility of its appearance in a certain locality regularly. The method a trapper employs in determining the route of a pack usually runs along the following lines. While trapping in a certain area he will probably see the trail of a pack leading over a ridge. He will then follow it for a number of miles over lakes and through valleys. For some three weeks not a sign of a wolf will be seen, but then he will suddenly find them back over approximately the same trail. When he finds this repeated for several years with very little variation, he will naturally assume that such a trail is an old one and part of the pack's hunting habit procedure. He will later find, to his satisfaction, that the same identical pack circled some ten miles away to the west, and by further checking with observers in the north and south he will discover that his route lies in almost perfectly with that of the observers. Then he has reasonable proof of the existence of one of the circular routes designated in the map. It is sometimes necessary to correlate the observations of several men in order to tie in a pack route, and although there is some room for conjecture (as there always is in determining game and predator behavior), such information is in the author's opinion as scientifically sound and based on observable fact as anything that could be worked out in a laboratory, the only difference being that here the laboratory is too big to enable easy checking.

Once the route of a pack is known, its members can be trapped quite easily as they use the same old trails in crossing rocky ridges and swamps, frequent the same coverts of game, and in every instance show a decided preference for familiar terrain. One such pass over the summit of a great divide just south of the Kawishowa River has been trapped steadily by one lone trapper for years (Denley). Every three weeks the pack returns, always crossing the same identical spot on the trail that they have used for generations.[7]

Game wardens during the month of January, 1933, (Hanson) counted twenty-four separate wolf tracks traveling north toward the Canadian border between Ramshead and Agnes Lake within a distance of three miles. Some

[6] Organization and range of pack are based upon:

		No. in pack
Denley—Stony River, Superior Forest,		1918—18
Linklater—Crooked Lake	" "	1922—20
Personal —Snowbank Lake	" "	1926— 7
" —Big Lake		1927— 5
" —Basswood and Knife		1928— 8
" —Burntside		1927— 4
" —Kennedy Lake		1921—20
" —Kawishowa River		1929— 9
Joe Kroll—Lac La Croix district		1930—24

[7] Trails and range of pack are based upon: Linklater, Crooked-Knife, 30 miles, 1920; Thomas Denley, Kawishowa and Stoney District, 1930; William Hanson, Basswood district; Personal, all regions.

were evidently traveling alone, others in groups of five to eight, all perhaps members of a large loosely organized pack running its accustomed route into the Quetico region to the north. In the Superior Area there are a number of these definite cruising trails, and each winter if conditions necessitate the organization of packs for more efficient hunting, the old members guide the new over the well-known routes.

The course a pack travels is in the shape of a great, uneven circle, the diameter of which is often thirty to fifty miles. The extent of the run depends on the supply of game. If game is plentiful, the circle may be small, if scarce, it may be several hundred miles in length. The fact that hunting is always easier in a region which has been undisturbed for several weeks may account at least partly for the great range of some of these hunting trails.

Storage Habits[8]

During the period when the pack is moving there is abundant evidence that more deer are killed than it will consume immediately. It is through this habit that the wolf brings upon itself condemnation, for it gives the impression that the members of the pack do not kill for the express purpose of food, but rather to satisfy the blood lust of the race. Each winter usually produces news stories of such killing, abundantly illustrated with pictures of mutilated carcasses of deer or moose. There is hardly a lake of any size in the Superior region which has not at least one carcass to its credit, and some of the larger bodies of water, such as Basswood, Vermillion and Lac La Croix, usually have quite a number. This evidence, to the casual observer, is conclusive that the timber wolf kills more than it needs during periods when food is plentiful and easy to get. Such adverse publicity is responsible for most of the clamor for additional predatory control.

Investigation, however, convinces the unbiased observer that such killing habits are purely storage acts, even though a number of deer may be left where they fell, with no evidence of feeding upon them or of any attempt to return later for that purpose. The habit of storage is deeply seated in all carnivores and is one of the primary laws of survival. There is no reason to suppose that the wolves of the Superior Area have suddenly varied from an age-old custom and kill to-day for an entirely different reason.[9]

The failure to return to their kills can only be explained by the many years of poisoning and trapping which have made them suspicious of every old carcass, even of the animals they have brought down themselves during the course of normal hunting. In other words, wolves kill instinctively as an act of storage and would return to their kills, had not experience instilled in them a fear of every carcass that has turned cold. During the heat of the chase, the old habit of slaughter for storage purposes asserts itself, and as a result many kills are made to-day which are not used. Passing by these same kills a night later, wolves, instead of feeding as they might be expected to do, often give them a wide berth, inhibited no doubt by past experience with poison and trap.

Under primitive conditions of sanctuary, in areas where man has not made his activities felt, it is reasonable to assume that wolves would return to kills sometime during the winter. The fact that very often they are trapped or poisoned by the use of old carcasses substantiates this belief. I am confident that if an area containing a normal population of deer and wolves was left unmolested for a long

[8] Storage facts are from personal observations; Thomas Denley, 1929–1930.

[9] Storage facts based upon miscellaneous trapper information, personal observations, 1920–1936.

period, evidence would soon accumulate, indicating that the wolves were returning regularly to their kills. Ability to do this without the danger of being caught or poisoned would soon restore the normal situation in which they would not kill more than needed. At the present time there is no question but that a ranging pack on the hunt, due to the fact that kills are not always utilized, creates an abnormal situation in which there is more actual loss of game than would be the case under conditions of equal sanctuary for both predators and herbivores.

Evidence as to Actual Kill of Deer

During the winter of 1914, two timber cruisers, in a very careful survey extending over a period of six months, counted 47 deer carcasses in a 60-square-mile area of game concentration in the Bear Trap River valley (Linklater). During the spring of 1931, 42 carcasses were counted in the Moose-Newfound area of approximately the same size (Hanson). Other similar areas, checked from year to year, also in regions of relative game abundance, point to the general conclusion that nowhere is the kill more than one deer per square mile and a quarter.[10]

The real wilderness region of the Superior National Forest which this study covers, as has been stated, is approximately 2,500 square miles in extent. If the estimate of one deer per $1\frac{1}{4}$ square miles held true for the entire region, the total kill by wolves would not exceed 2,000 animals annually, it being assumed that very few if any deer are taken during the warm months of the year. Because of the fact, however, that hundreds of square miles during the snow months are practically barren and devoid of any game and that the above estimates of kill were all made in areas of game concentration, it is evident that 2,000 is too high a figure. A total kill of 1,500 deer would be within reason. If the wolf population is 250 animals, the kill per wolf would be six deer per year or one deer every two months.

Deer and Moose Populations

In order that the relationship between the timber wolf and the herbivores be understood from the standpoint of the influence of one form upon the numbers of the other, it is now necessary to arrive at an approximate figure as to the actual resident population of big game animals in the Superior Area. As has been intimated, in new and freshly logged or burned country, such as large sections here represent, browsing conditions are particularly favorable for the propagation of deer. In view of investigations which have been carried on elsewhere on the carrying capacity of forests, the wilderness area could support roughly 35,000 animals, were it not for the climatic factors of snowfall and the consequent loss of browsing opportunity. Any worthwhile estimate of game-carrying capacity must be based not on seasonal capacity but must cover the entire year. In view of the fact that much of the food is unavailable for five months of the year in northern Minnesota and that great areas during the winter season are therefore not only barren but devoid of protection from storms, it is safe to say that the carrying capacity of this area would not be much more than 20,000 animals. From a variety of independent estimates by local authorities, substantiated by personal observations extending over a period of years, the figure of 20,000, or one deer to 80 acres, seems reasonable. Moose are estimated as close to 1,000 or

[10] Storage count and evidence of kill are from: Matt Wiirimaa, Jack Linklater, Agnes Lake district, December to March, 1914, 47 carcasses, 6 townships; Gay Gilbertson, warden, Newfound Lake Area, December to April, 1931, 42 carcasses, 6 townships; J. M. Walley, superintendent of Chippewa National Forest, January, 1930, 1 carcass to 9 square miles; R. A. Zeller, superintendent of Superior, very few, only 200 carcasses reported, 1930.

one to 1,600 acres. Figured in larger units, it amounts to 8 deer per square mile and 1 moose per $2\frac{1}{2}$ square miles.[11]

In order to attain a relative idea of the big game-supporting capacity of this region as compared with other somewhat similar areas, it may be interesting to mention the observations of others. Dr. C. A. Schenk advocated limiting the number of deer in the Southern Appalachian Forest to one to 166 acres. In Pennsylvania to-day, Henry E. Clepper states that the average carrying capacity is one deer to forty acres. In Europe, where browsing conditions are entirely different from those found in the United States, it is the consensus of opinion of gamekeepers and foresters that it takes from forty to fifty acres to support a deer the year round. Surveying all figures and estimates available, the average of one deer to every fifty or sixty acres seems to be the most common. The Superior Area with its young and vigorous mixed deciduous growth could therefore support a greater deer and moose population than it actually does, were climatic conditions entirely favorable.

General Conclusions

Proponents of predatory animal extermination base their claims on the numbers of big game animals sacrificed every year as food. To combat and refute these claims it must not only be known how many deer and moose are killed, but how great a drain a herd can stand without serious diminution of its breeding stock. It becomes then a problem in which one set of figures is balanced against another, a problem in which the burden of proof is placed upon those who believe that predators have their place.

Since the total deer population of the Superior Area is in the neighborhood of 20,000 animals, and as authoritative research has estimated they can stand a drain of 20 per cent. without diminution of adequate breeding stock, it means that the deer herd could stand an annual loss of about 4,000 animals. Inasmuch as the deer and moose populations seem to be holding their own and in many parts of the forest actually increasing, it may be inferred that no more than this number are being lost each year. It may also be assumed that at least half of this number can be accounted for either because of old age, disease or the fact that a large number are either killed or wounded as they stray beyond the refuge lines during the biennial hunting season. It has been estimated that wolves are directly responsible for some 1,500 deer killings annually, which comes well below their share of the possible 20 per cent. drain.

Those who hold that wolves will soon mean the complete extermination of deer and moose are still influenced by the oft-quoted estimate that each wolf kills a deer a week. If this were so, and if the wolf population is 250 animals, as estimated, they would exact at that rate a toll of 1,000 deer per month or 12,000 per year, 60 per cent. of the total herd, an absolutely untenable figure.

The presence of the timber wolf in the Superior Area, instead of being a hazard, is a distinct asset to big game types. Long investigation indicates that the great majority of the killings are of old, diseased or crippled animals. Such purely salvage killings are assuredly not detrimental to either deer or moose, for without the constant elimination of the unfit the breeding stock would suffer. Furthermore, the wolf is a natural stimulus to a herd's alertness and injects the primitive element of danger without which most big game animals lose much of their natural charm.

Large wilderness areas such as the Superior Forest demonstrate that sanc-

[11] Deer and moose populations are from personal observations, 1920–1936, collaboration with the above observers and many others over a period of years.

tuary can be successfully given to both herbivores and carnivores without danger of decimation of the big game types. The timber wolf is an integral part of the wilderness community, the destruction of which would destroy the fine balance between related forms. To eliminate as vital a relationship as exists between predatory forms and the animals they prey upon, to destroy a mutual dependence, means that artificiality has entered the wilderness picture.

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SHELLFISH FOR FOOD

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She is neither fish nor flesh nor good red herring.
—JOHN HEYWOOD

That man had sure a palate covered o'er
With brass or steel, that on the rocky shore
First broke the oozy oyster's pearly coat
And risked the living morsel down his throat.
—JOHN GAY

FROM times before history began man has known the value and probably appreciated the flavor of shellfish as food. Ancient kitchen middens found near the seacoasts in many parts of the world from Sweden and the Aleutian Islands to Tierra del Fuego and Tasmania, where middens are still accumulating, are made up mainly of the shells of molluscs eaten by men of the Neolithic Age, who cast the empty tests upon these refuse heaps along with the bones of fish, birds and mammals.

Through centuries of advance toward established civilization, man has adapted to his use and introduced into cultivation many plants and animals which were quite unknown to his forbears as possible sources of food. Opportunity of choice and superabundance of supply have developed a taste both discriminating and exacting in its demand for variety and flavor and an appetite stimulated beyond the requirements of need. The time-honored method of trial and error has eliminated a good many items from the modern table d'hôte which less critical tastes considered dainty and delicious. The years are long since eggs of ants and the fat, white larvae of beetles were generally regarded as tidbits for honored guests and favored chieftains; still longer are the years since a hungry hunter along some ocean beach found and ate his fill of a "Whale that died and foundered after a month at sea," and soon thereafter wondered why the gods had visited him with a painful affliction.

Living races all over the world to-day use for food the molluscs of their seacoasts and estuaries, their rivers and even their forests and fields. Molluscan prestige has increased with growing appreciation of the succulent quality and unique flavor of shellfish which have traveled in an artificially arctic atmosphere far from their native habitats. Sophisticated society restricts the use of molluscs as food to a few established favorites; many other equally deserving varieties, from unfamiliarity alone, are repugnant to all but the initiate. Travelers to the Orient and less far afield sometimes try a salad of conch, a stew of squid and the novel bonne bouche of "escargots" steamed in their shells and offered with a delectable dressing of garlic-seasoned mayonnaise. In some remote parts of the world where the food balance between necessity and supply is always precarious, the native molluscs of land and water help to maintain a margin of safety as to quantity and an essential element of quality.

Throughout the whole South Seas the octopus and the squid are hunted and captured for food. Native fishermen with poised spears wade along the coral reefs peering through the clear water for an octopus partly hidden in his lair. The spears are thrown with marvelous accuracy, and usually with results wholly satisfactory to the fishermen. Among the Fiji and Melanesian Islands and in the Moluccas, where the nautilus is fairly abundant, these creatures are taken in cages not unlike the familiar cylindrical lobster pots. The traps are baited with

fish, anchored in a few fathoms of water and drawn up to be inspected each day. In Naples and Honolulu, as in Bangkok and Yokohama, octopus and squid, both fresh and dried, are regular offerings in the fish markets. From China and Japan dried cephalopods are exported to other countries to meet the demand of their oriental populations. Even faraway Newfoundland has a small export trade with the Orient in dried squid.

In the countries around the Mediterranean Sea from Spain and Morocco to the Levant, natives eat the animals of the moon shell, *Natica; Turbo,* the turban shell; *Murex,* the "purple fish" which furnished the Tyrian dye; the *Triton,* named for the sea-god son of Poseidon and Amphitrite, who controlled the waves at will by blowing upon his conch-shell trumpet; *Strombus,* the top shell; *Melongena; Cardita* and *Pholas,* the latter known in the markets as the "sea-date" or "datefish" because of its cylindrical shape. At Key West and in the Bahamas the queen conch, *Strombus gigas,* is a staple of food for man and a highly successful bait for fish. Prepared in accord with various recipes, undisguised or as an "à la," it appears on the usual menu, but its leathery quality and peppery taste do not often please the unaccustomed appetite.

West Indian Negroes collect large chitons from the rocks along the island coasts, cut off the muscular foot of the animal, call it "beef," and eat it in the natural state or compounded into a savory loblolly with vegetables and seasonings. *Pholas costata,* the angel's wing, is esteemed in Cuba as we value the Venus clam, and on many South Florida beaches the great heart clam, *Cardium robustum,* is gathered by fishermen who make from it a wholesome and palatable chowder. The herring gulls, which winter in the South, also appreciate this splendid *Cardium.* They fly high above the beaches with the heavy molluscs in their beaks, drop them to break the shells, and if the first effort is not successful it is repeated until the shell is cracked by the impact of the fall and the enterprising birds enjoy their reward of fresh, delicious sea food.

Four-footed animals of one kind and another have learned that clams and oysters are good eating. The coons of southern Florida and the Keys are so fond of the oysters that grow on the roots and submerged branches of the mangrove trees and on the reefs in shallow water that these molluscs are known locally as "coon oysters." Up in the Bay of Fundy herds of pigs used to swarm out over the flats at low tide to root for buried clams. At the turn of the tide they turned too, and ran squealing for dear life to keep ahead of the rising water.

In southern Florida and at Panama the slender razor clam, *Ensis,* and the little coquina clam, *Donax* (in size and weight one of the smallest of its tribe), are considered delicacies. The fortunate visitor to these coasts who is served with a bowl of coquina broth is introduced to a new and unique flavor. He will probably take a few cans of the broth away with him.

All along the Atlantic seaboard, around peninsular Florida and into the Gulf of Mexico, common clams of several varieties are high in popular esteem. At the North, the old Indian name "quahog" still means the hard-shelled *Venus mercenaria,* the money shell from which purple and white wampum were made, and whose small ones are the "little-neck clams," a name supposedly derived from Little Point, Long Island. The soft-shelled "manninose" is *Mya arenaria.* It has been abundant from Pleistocene times up to the present. A congenial beach station along the North Atlantic coast may be almost paved with succeeding generations of this mollusc. *Spissula solidissima* is the "surf clam" of the New

England coast, not generally liked; and its smaller southern variety is not eaten at all save by other creatures of the sea. "Cherrystone" is a name to conjure up delightful recollections of tender clams served icy cold on the half shell. In clam fritters at Wachapreague and Chincoteague, in clambakes on the Jersey coast and Long Island, steamed or in chowder, as a joy to the epicure, it is second only to the oyster.

Off the west coast of Florida, southward from Marco Pass, are the most extensive clam beds in the world; and the nearby little towns of Marco and Caxambas receive the shellfish brought ashore in bargeloads from dredges which operate a few miles off shore. These clam beds are protected by the government, and it is unlawful to take clams of less than a specified size.

On the Pacific coast enormous numbers of "sea ears," *Abalone,* are taken from their rocky habitat between high and low water marks. The animals are removed from the shells, strung on cords, dried and sold to oriental peoples living on both sides of the Pacific, while the beautiful iridescent shells are extensively used in the manufacture of souvenirs and novelties. Farther north the great clam, *Panopaea,* which passes its life buried in the sea bottom of the intertidal zone, is said to sell in the markets of Seattle at a dollar apiece. California's "flat clam" is a *Semele,* and the cold-water-loving species, *Glycimeris generosa,* is the "geoduck," an important item in the food supply of the Northwest Coast Indians.

The great *Tridacna gigas* of the far Orient, not uncommon on the Great Barrier Reef of Australia and on to the Solomon Islands, the Moluccas and the Philippines, is not only the largest of living molluscs, but it also attains to man's age of threescore years and ten. One clam will yield twenty pounds of edible flesh, and the huge bivalve shell may weigh five hundred pounds. The British Museum has two specimens of single valves which weigh respectively one hundred and fifty-four and one hundred and fifty-six pounds. The pure white, beautifully scalloped and deeply concave valves have been used in churches as benetiers for holy water—St. Sulpice in Paris has one—and as basins for garden fountains.

Whelks of the family Buccinidae are eaten as a matter of course in the British Isles, and nearly every fishmonger's shop in London and around the coast offers the periwinkle ready cooked in its shell at "tuppence the pint." Tiny cockles are steamed and served with a shake of pepper and a sprinkle of vinegar to be eaten on the spot or carried away. Great Britain's "gaper" clam, allied to the genus *Mya,* is not valued as food. Nor is the channel abalone, *Haliotis tuberculata,* the "ormer," presently consumed in the Channel Islands where it was once quite generally eaten.

Mussels are also consumed in quantities in Great Britain, but are not cultivated for market demand as they are on the French and Belgian coasts across the English Channel, where mussel farming is practiced on a large scale and by a modification of a method said to have been devised by an Irishman who was shipwrecked on the coast of France in the year 1235. He set nets attached to stakes for the capture of sea birds, but soon found that the mussels which attached themselves to his stakes afforded a more nutritious and palatable provender. Mussel culture by the "bouchot" method, as practiced to-day, has developed from Irish Walton's primitive nets and stakes. The mussels which were lifesaving food to him have become the foundation of the justly famous "Soupe au Moules."

France and some other parts of Europe have their "escargotieres" or snail gardens, where snails are bred and fat-

tened for the market. We have Pliny the elder as authority for the existence of snail preserves at Tarquinium, in Italy, about the year 50 B.C., and Pliny the younger, in his Epistles, chides a friend for going off to eat sea urchins, scallops and oysters when he had agreed to dine with him on three snails, two eggs and a lettuce apiece, with mead, snow and barley water, olives and beet-root with gourds and truffles.

Horace tells us that—

> 'Tis best with roasted shrimps and Afric snails
> To rouse your drinker when his vigor fails.

This record of practice in Horatian Rome is associated with Pliny's advice for the dose of "an uneven number of snails" as a remedy for coughs and stomachache; and with his cure for headache, which was a plaster made of decapitated slugs applied to the forehead. Belief in the efficacy of snails eaten alive and whole, or boiled in milk or wine as a prophylactic and cure for consumption, asthma, corns, ague and dropsy, persists to present times among some isolated peoples whose unfortunate weaklings are given daily doses of snails as a tonic treatment. Still more astonishing is the statement that emulsified snails have been most successfully used in the manufacture of synthetic cream!

From the England of George the Third a cure for warts, which was old even then, was brought to America, and may still be in use. A snail with a black shell must be found and rubbed on each wart separately, the while saying the magic couplet—

> Wart, wart, on the snail's shell black,
> Go away soon and never come back.

Then the snail must be placed upon a branch of tree or bush and tacked down with as many thorns as there are warts to conjure away. As the snail dies and disappears the warts will vanish. This formula was tried with full faith and confidence in the writer's little girlhood. With the help of an old colored servant a black snail was found, the warts were well rubbed, and the small girl ran round and round the house chanting the magic rune. The snail's shell was tacked with thorns to a yellow rose bush, and when the shell was empty the warts were gone and forgotten.

The tender and delicious scallop is probably more esteemed in the United States than elsewhere in the world, although its range of distribution is throughout the Seven Seas. The Gulf of St. Lawrence and the Labrador coast have the great northern scallop, *Pecten tunicatus,* peculiarly delicious but not very abundant. The Atlantic coast species is *Pecten irradians,* and in the Gulf of Mexico lives its southern congener, *Pecten dislocatus.* Both species are so much in demand that it has become profitable to substitute for the firm, shining-white muscle of the true scallop the corresponding part of some other mollusc, notably *Atrina,* and even to punch out with a specially devised instrument appropriately-sized pieces of flounder and other dry and white-fleshed fish. The true scallop is the adductor muscle of the bivalve, whose function is to draw together the two valves of the shell and maintain them in apposition. Only this muscle is used for food, all other parts of the animal are discarded. Nova Scotia's scallop industry employs a special fleet of boats and sends three fourths of its annual catch to New York City.

There is evidence that the scallop's lifespan is from two to three years. Sexual maturity is reached in a year, and one individual scallop may be responsible for more than a million eggs discharged into the water at one spawning. The eggs are spherical and measure one six thousandth of an inch in diameter.

Fresh-water shellfishes are generally

tasteless and insipid, and have never been regarded as desirable foods, except in circumstances where necessity rather than choice must be considered. The fluviatile mussel, *Anodonta edulis,* is cultivated for food in some parts of China. African natives make use of their river species to some extent, and in some of the East and West Indies the natives eat the molluscs of their streams; but the principal use man has made of fresh-water mussels is the utilization of the nacreous linings of their shells for the manufacture of buttons and other small articles of utility and beauty.

Of all the different varieties of shellfish adapted to gratify an appetite for variety and delicate flavor, the oyster stands easily at the head of the list. As long ago as the first century B.C., a certain Roman, one Sergius Oratus, cultivated oysters on a large scale as a money-making venture. His nurseries were in the Lucrine Lake, not very far from Rome, and the delicacy of his oysters was considered to be so superior that those brought from other beds in Italy, and even from faraway Britain, were put in his "vivaria" to acquire the Lucrine flavor.

Like the Lucrine beds of old Italy, certain localities in America are to-day famous for the flavor of their oysters. Bluepoints, Chesapeake Bays, Cotuits, Wachapreagues and Lynnhavens, all have their partisans who declare that their favorites surpass those of any other beds. In the far South it is believed and staunchly maintained that those oysters, which grow naturally on the aerial roots and drooping branches of the mangrove trees, when eaten freshly roasted in the ashes of a campfire, excel any Bluepoints ever served in the half shell on ice in a metropolitan restaurant.

The indigenous, small and thin-shelled Pacific oyster, *Ostraea lurida,* has only a local reputation, and has never reached the commercial importance of its Atlantic cousin. Marketable oysters are usually from planted beds, and neither the yield nor the value is very great. The anecdote of the young lady from California, who ordered two dozen fried Chesapeake oysters in a Baltimore restaurant, suggests a contrast in bulk at least.

The European oyster, *Ostraea edulis,* is native from Norway to Italy, but the market demand is almost wholly supplied from artificially cultivated stock matured in shoal waters along the coasts. French ostreiculture culminated in Normandy in the production of that special delight of the epicure, the "green oyster," whose pedigree as a delicacy without peer goes back at least to 1713, when it was served as a rare luxury at a banquet given by an ambassador to the Hague.

The British Isles have extensive oyster banks in the Thames estuary, and oyster farms at Whitstable and other places along the English coast; near Edinburgh in Scotland, and in Ireland's County Down.

The British oyster has a venerable tradition. The Piltdown men may have found it good. Men of Caesar's legions enjoyed it, and among the English of three hundred odd years ago there was a well-known and accepted proverb that "Whoever eats oysters on St. James's Day will never want money." In point of fact, the oyster-eating season in London was inaugurated on old St. James's Day, the fifth of August. Not quite in conformity with this traditional date is the record of a custom which was ancient at that time. During the first few days of the oyster season, children of the humble classes would collect the shells cast out from taverns and fishmongers' booths and build them into rude heaps. By the time of St. James's Day the little piles would be complete, with a candle stuck in the top of each, ready to be lighted at twilight and watched by the young builders, who claimed a penny from each passing stranger, professedly

to keep the votive candle burning. No doubt this is a survival of ancestral custom before the Reformation, perhaps brought from the shrine of St. Iago in Spain.

In the year 1675, during Charles the Second's reign, a certain Mr. Walter Tucker, of Lyme, Dorset, was billed and subsequently paid for:

30 lobsters	L 1	10	0
6 crabs	0	6	0
100 scallops	0	5	0
300 oysters	0	4	0
50 oranges	0	2	0
	L 2	7	0.

"Proud Preston," in Lancashire, boasted for seventy years of its "Oyster and Parched Pea Club." Records of the club for the year 1773 name among its staff of officers one called "Oystericus," to whom was entrusted the responsibility of looking after the oysters, which at that time were sent by "fleet" from London.

From April to August is the spawning time of the oyster in temperate latitudes. During this spawning period the oysters are said to be "in the milk" and are unfit for food. Here is the origin of the ban upon eating oysters during the months which do not include the letter "r" in their spelling. In the South the spawning process commences earlier in the season, but in any latitude warm weather is absolutely essential to the survival of the "spat," as the newly hatched young are called.

For a time the young oysters swim freely about, and during this stage of their lives they are a part of the drifting multitudes of tiny creatures which form the basic food of all animals that live in the seas. Very soon the little cilia, or hairs, by whose movements the young molluscs are able to swim about, are lost, and the baby oysters settle down to sedentary life, becoming firmly attached by the left, or under valve of their shells to some solid object in the water where they happen to be when this change occurs.

Their rate of growth is rapid. From microscopic smallness, within a year a diameter of an inch has been attained, and this rate of growth continues to the third or fourth year. Subsequent increase takes place more slowly, but quite roughly speaking, an oyster is as many years old as its shell is inches wide. Five years develops an oyster to its succulent best, but the natural span of life is believed to be about ten years. Reproductive activity commences about the third year, and it is estimated that each individual oyster produces from three hundred thousand to sixty million young, most of which, however, do not escape their many enemies to reach the period of maturity.

Oysters are said to grow best in muddy water and to breed best in clear water. The tidal alternations, bringing in clear water from the open sea and draining from flats and bayous water rich in sediment and organic matter, seem to provide the happy medium in which the Atlantic species, *Ostraea virginica,* attains perfection.

Not only in infancy is the oyster beset by enemies. All through life it escapes only by good luck from the attacks of starfish and of such predatory, carnivorous molluscs as the oyster drills, which play so much havoc in the oyster beds that special nets and dredges have been devised to capture these active invaders. Where oysters and mussels grow together, the oyster must wage a constant passive fight against starvation and suffocation, usually to its own discomfiture, since the beds are often smothered by the rapid overgrowth of their unwelcome neighbors. The parasitic boring sponge, *Cliona,* burrows into the oyster shells, pitting them with small round holes, and forcing any unfortunate oyster to expend all his energies toward maintaining a shelter for his soft and defenceless body.

Nor does this inventory complete the tally of creatures which prey upon the helpless oysters. Disease germs attack them, birds prey upon them, small animals and fish eat them, and man himself is the arch enemy of all.

Oyster culture in the United States was estimated at the turn of the century to have a value to growers of $14,211,713; to give employment to more than 60,000 people during the shucking season, and to produce about 26,453,146 bushels of oysters, principally for home consumption. About 40 per cent. of these oysters are from natural beds. Chesapeake Bay is the most productive area, with Long Island Sound taking second place. Baltimore is the most important center of distribution in the country, but New York City consumes the greatest quantity and has a considerable export trade to Europe.

Throughout the Japanese Archipelago, *Ostraea cuculata* thrives abundantly in natural beds in shallow and brackish water. The adjacent deep waters produce the great-sized *Ostraea gigas*. Molluscan culture both for food and pearl production has been carried to a high degree of development in Japan and is an important industry.

No one can tell an epicure how best to prepare his oysters. No less than forty recipes are contained in one very old cook book, and "The Cook's Oracle," available both in Boston and London more than a hundred years ago, has this to say:

> Common people are indifferent about *the manner of opening Oysters*, and the time of eating them after they are opened; nothing however is more important in the eyes of the experienced Oyster eater. Those who wish to enjoy this delicious restorative in its utmost perfection must *eat it the moment* it is opened, and with its own gravy in the under shell; if not *Eaten while absolutely Alive*, its flavor and spirit is lost. . . . The true lover of an Oyster will have some regard for the feelings of his little favorite, and will never abandon it to the mercy of a bungling operator, but will open it himself, and contrive to detach the Fish from the shell so dexterously that the Oyster is hardly conscious that he has been ejected from his Lodging, till he feels the teeth of the piscivorous Gourmand tickling him to death.

This seems fairly to express the opinion of connoisseurs for more than two thousand years, and the "piscivorous Gourmands" of our own time are rejoiced to know that soon they may have their oysters in the full blush of living perfection, however far removed from the seacoast they may dwell. Investigational Report No. 15, of the United States Bureau of Fisheries, by V. Koehring and H. F. Prytherch, describes a method, protected by patent, by which oysters may be narcotized before removal from their shells, and reawakened to full activity without experiencing the shock of the "shucking" process of suffering any injury to the soft parts. The oysters are anesthetized in either fresh or salt water to which has been added a small quantity of such an acid as hydrochloric or acetic. A chemical reaction with the lime salts of the oyster shells releases carbon dioxide into the water, and it is this agent which so relaxes the muscle of the oyster that the shell gapes widely. Dr. Prytherch says it may prove desirable to employ ethyl alcohol for narcotizing and opening oysters, as his investigations have shown it to be especially effective; so where the American Indian solved this problem by the use of fire, the modern oyster farmer may go him one better and employ "firewater" to facilitate removal of the live meat of this delicious shellfish.

SEX AND GENES

By Dr. W. E. CASTLE
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SEXUALITY is one of the most fundamental and general of the peculiarities of living things. In each species of animal or plant there are produced reproductive cells of two different sorts, which have an attraction for each other, so that they come together in pairs and fuse, and out of the product of such a fusion develops a new individual of the species.

Among animals the uniting cells are known as egg and sperm, respectively. Individuals which produce eggs are known as females, those which produce sperms are known as males. Other differences between the sexes are secondary and dependent upon the primary difference, egg production or sperm production. Such secondary differences arise largely through the action of the hormones, chemical substances which are produced by the same body structures which produce the eggs or sperm and which substances profoundly affect the constitution and behavior of the individual.

In plants as well as animals there are produced two kinds of reproductive cells, which we may call male and female, respectively. In some species they are produced as in animals, by male and female parents, respectively, but more frequently in the higher plants the same parent produces both sorts of reproductive cells in the same flower; what corresponds with the sperms of animals being produced by pollen grains, and what corresponds with the eggs of animals being produced in the ovary of the flower.

But whether we are dealing with animals or with plants, there is found to exist an attraction between the male and the female reproductive cells in each species, so that they strive to unite. But as soon as this union is accomplished, the attraction ceases to exist. It is as if egg and sperm bore opposite electrical charges, one plus, the other minus. The moment egg and sperm unite, the fusion product becomes neutral.

Fertilization of sea-urchin eggs is a favorite and much-studied subject illustrating this matter, since the whole process takes place outside the bodies of the parents in sea-water and can be observed continuously under the microscope. As a sperm approaches an egg, the latter protrudes a little elevation of its surface toward the sperm, and into this the head of the sperm penetrates. Instantly the eggs loses its attraction for sperms and secretes a superficial membrane which serves effectively to exclude other sperms. The pronucleus of the egg still retains, nevertheless, an attraction for a sperm pronucleus into which the head of the sperm has metamorphosed. These two pronuclei come together within the egg and fuse, and out of this fusion nucleus, the new individual which develops from the egg derives its nuclear material and so its inheritance from its two parents in equal measure.

In the fertilization of a sea-urchin egg, as just described, we must carefully distinguish two processes of attraction between male and female elements; first, the attraction between egg and sperm which is extinguished or satisfied the moment a sperm enters the egg, or (if you prefer so to state the case) the moment the egg *captures* a sperm. Secondly, there exists an attraction between egg nucleus and sperm nucleus which is later extinguished or satisfied when those nuclei have united and intermingled their substance.

It is an alluring but possibly fanciful thought to regard these attractions as based on opposite electrical charges which are neutralized when a union is accomplished, though it may well be chemical rather than electrical differences which form the basis of the attraction. If that or something analogous to it actually exists, we can think of the sperm and the nucleus which it carries as both negatively charged, whereas the egg and its contained pronucleus are positively charged, or *vice versa*. These opposite charges serve first to bring the sperm into the egg, when the egg-sperm differential charge disappears, then to bring the two pronuclei together, after which the nuclear differential charge disappears and the fusion nucleus goes on its way to develop a new individual body.

The process of fertilization in a flowering plant may be regarded in a similar way. The male element in this case is a pollen grain produced in the anther of a blossom. Falling on the receptive stigma of a flower, it is stimulated to rapid germination. Its fungus-like pollen tube penetrates downward through the style to the ovary of the flower, its growth guided and accelerated apparently by a substance or substances given off from the ovary. It may have to follow a devious course to reach the ovary, but it does not fail to find its way to the minute micropyle which would admit it to the presence of the ovosac in which an egg cell is maturing. Again, as in the fertilization of an animal egg, one may distinguish a two-fold attraction: first, between the pollen tube and the ovosac, which is extinguished or satisfied when the two meet. There may be many pollen tubes growing through the style of the flower toward its ovary, but only one may reach each ovule, then the attractiveness of that ovule ceases, as if its positive charge were neutralized. Secondly, there is an attraction between the egg nucleus and a pollen nucleus which is discharged from the tip of the pollen tube into the ovosac. This attraction also is extinguished or satisfied by the fusion of egg nucleus and pollen nucleus to form a fusion nucleus that produces an embryo, a rudimentary new individual of the species.

In many flowering plants, what is called a double fertilization occurs. The pollen tube contains two gametic nuclei, each of which corresponds with the sperm head of an animal spermatozoon. One of them (it is apparently a matter of chance which) fertilizes an egg nucleus, as already stated, to form the embryo; the other unites with one or more other nuclei, sister products to the egg nucleus but destined not to form an embryo, but "endosperm," a reserve of food stored along with the embryo in the seed. The endosperm nucleus or nuclei of the ovosac thus have a sex attraction similar to that of the egg nucleus, and this is similarly satisfied or extinguished by union with a pollen tube nucleus. They carry the same sort of a charge as the egg nucleus and the ovary, contrary to that carried by the pollen tube and its contained nuclei. They are potential egg cells and like other egg cells have an affinity for male gametes of the species.

The affinity between egg and sperm is not restricted to the gametes of a single species. The eggs of one species attract and may unite with sperms of a different species. This shows that the nature of the differentiation of male from female is the same in different species. Male gametes in different species behave as if they all carried a negative charge which gave them an affinity for all positively charged or female gametes.

When the egg of one species is fertilized by a sperm of a different species and thus produces an embryo, we call such an embryo a hybrid, and it partakes of the properties of both species. Such hybrid offspring are frequently vigorous but commonly sterile. More often they are incapable of survival. The more distant the relationship between the species crossed, the less likelihood is there that

offspring capable of survival will be produced.

Two species of rat sometimes reared in captivity, the Norway rat, best known in the tame white variety, and the so-called Alexandrian or black rat, can with difficulty be crossed. Hybrid embryos are produced which, however, survive only through about half of the normal gestation period, then perish. No living hybrids have ever been produced experimentally.

Mouse and rat, less closely related, are assigned at present to different genera, and no hybrids between them, even in the early stages of development, have been produced, although several investigators have attempted to produce them.

Many years ago, in the early days of Mendelism, I published an essay on the heredity of sex, in which I advanced the then novel idea that sex is inherited in accordance with Mendel's law, like other characters of animals and plants. I supposed that the attraction which exists between an egg and a sperm was due to what we should now call their sex genes, and that only such unions would occur as brought together contrary sex tendencies or determiners. It was suggested that all diploid individuals (products of fertilization) were thus sex-heterozygotes which had inherited maleness from one parent, femaleness from the other, and would in turn transmit each of these in half of its gametes.

Thus there would be eggs transmitting maleness and other eggs transmitting femaleness; and also sperms transmitting maleness and other sperms transmitting femaleness. But only heterozygous unions would occur, since a male egg would not attract a male sperm, but only female sperm, and *vice versa*.

This hypothesis proved to be only half true. There are indeed species, like the fly Drosophila and the mammals in general, in which sperms transmit, half of them femaleness in an X-chromosome, and half of them maleness in a Y-chromosome, but in these same species *all* eggs transmit femaleness in an X-chromosome, which is contrary to my hypothesis that both sexes are sex-heterozygotes.

There are other species, such as the moths among insects and birds in general among the vertebrates, in which eggs transmit half of them femaleness in an X-chromosome and half of them maleness in a Y-chromosome, but these same species transmit in their sperms only maleness in a Y-chromosome, which again is contrary to the hypothesis that both sexes are sex-heterozygotes.

The truth is that we must distinguish between the *sex reaction* of a gamete and the *sex gene* which it transmits. The two may or may not be alike. All sperms are, in reaction, male gametes and are attracted by female gametes, eggs, but in the case of mammals only half of the sperms *transmit* a male sex gene, the other half transmit a female sex gene. On the other hand, the eggs of mammals which in their sex-reaction are female regularly transmit also a female sex-gene. Thus the offspring of mammals are some of them male, some of them female in their sex-reaction as individuals and in the sex-reaction of the gametes which they produce, but in the sex-genes which they transmit in those gametes, sperms are of two sorts, male producing and female producing, respectively, whereas all eggs are female producing.

My original hypothesis, that sex inheritance is Mendelian, has proved correct as regards one important feature of Mendelian inheritance, dominance. When a sex heterozygote is produced, one in which contrary sex tendencies are united, the character of one sex dominates, to the exclusion of that of the other. Thus in Drosophila and mammals the sex heterozygote is a male, that is, has a male sex-reaction and produces sperms, maleness being dominant, femaleness recessive.

On the other hand, in birds and moths,

femaleness dominates in the heterozygous sex, which is female in sex-reaction and gamete production, maleness being recessive and expressing itself only in homozygotes, males.

The two radically different systems of sex determination found among animals are thus seen to differ fundamentally in the matter of dominance, *i.e.*, as regards the relative strength of the sex genes. In mammals maleness is dominant, and the genetic determination of the sex of offspring rests with the sperm; in birds femaleness is dominant and the genetic determination of the sex of offspring rests with the egg.

Among fresh-water fishes, both systems of sex determination occur in different species of the same genus, and it is possible to cross these. An instructive study of reciprocal hybrids within this group has been made by Dr. Bellamy on the Los Angeles campus of the university. He crossed *Platypoecilus maculatus* in which femaleness is dominant with *P. variatus*, in which maleness is dominant. Using the female of one species in making the cross, offspring of both sexes were produced. Using the female of the other species, only male offspring were produced.

The cross which produced only male offspring was made between the sex-homozygotes of both species. Using **X** to designate female sex-gene content and Y to designate male sex-gene content, we may express this cross thus:

♀ parent (egg producer)	♂ parent (sperm producer)
XX	YY
eggs all X	sperms all Y

The zygotes which result are all XY and *male*, maleness dominating and thus indicating male dominance to be the rule when the special strong genes of each species are not present.

In the reciprocal cross both parents were sex-heterozygotes, maleness being dominant in one (the male parent),

	♂ parent (sperm producer)	♀ parent (egg producer)
	XY	X**Y**
Zygotes	**X**X XY **XY** Y**Y**	
	♀ ♂ ♂? ♂	
	or intersex	

femaleness in the other (the female parent). Four kinds of combinations are theoretically possible. One will be a homozygous female (**X**X), another a homozygous male (Y**Y**). The other two will be heterozygotes. The combination XY will be male in sex differentiation, since, as we saw in cross 1, when a weak X is combined with a weak Y, the latter dominates. What will be the sex of a strong **X** combined with a strong **Y** has not been experimentally determined, but we should expect it to be either male or an intersex. It would appear accordingly that this cross between sex heterozygotes of two species differing in regard to sex dominance should produce chiefly male offspring, which was actually the result observed by Bellamy.

When do eggs and sperm acquire their respective plus and minus qualities, which cause them to attract each other? It was formerly thought that this occurred at the maturation of the germ cells, when they pass by a reduction division from the diploid or 2 n state in which each sort of chromosome is represented in duplicate, to the haploid or n state in which only one of each sort of chromosome is present. It was thought that the haploid state was itself a prerequisite to sex attraction on the part of the gamete. But this idea was shown to be erroneous when the Marchals were able in the case of mosses to induce the formation of gametes both by diploid or 2 n tissues and also by tetraploid or 4 n cells. Subsequently, both in flowering plants and in animals, gametes with two, three or more sets of chromosomes have been produced by various agencies, especially by subnormal or supernormal temperatures (cold or heat), the effect of which

has been to induce an uncompleted cell division, in which chromosome splitting occurs without the usual separation of the duplicated chromosomes into different cells. The result is the production of a cell with double the normal chromosome number which is capable of developing into a gamete. If such a diploid gamete unites with a normal haploid gamete, a triploid zygote results, in which each sort of chromosome is three times represented. And if two diploid gametes unite with each other, a tetraploid (4n) zygote results.

We thus are shown that development of the opposite and attracting qualities of gametes occurs whenever gametes are formed, irrespective of the number of chromosomes involved. Sex attraction is accordingly a somatic (cytoplasmic) differentiation involving the development of opposite (+ or –) characteristics in two classes of cells, the chromosome numbers of which, though normally haploid, *may be* diploid, triploid or irregularly haploid, with one or more chromosomes in duplicate or altogether wanting, conditions known as n + 1, n + 2, etc., or n – 1, n – 2, etc.

How is the somatic character of a gamete determined, *i.e.*, its sex reaction in distinction from the sex-gene which it transmits? Its somatic character is in agreement with and presumably determined by the sex of the parent which produces the gametes. A female parent produces eggs, a male parent produces sperm. But the sex of the parent individual itself was determined in the previous generation by the sex-gene content of gametes which united to form that parent. Only one seeming exception to this rule occurs to me. This is found in the case of hymenoptera, among the insects, in which the influence of the gametic nuclei is *always* female, never male. Yet male individuals are produced among the hymenoptera which furnish sperm for the fertilization of eggs. Such sperm, however, transmit only a female influence in the sex determination of offspring. They are only *somatically* male. How do they get that character? They develop from unfertilized eggs and so contain only nuclear material derived from their mothers, and this is female in its sex gene content. It must be, therefore, that the sex reaction of individuals which develop from unfertilized eggs is due to the nature of the egg cytoplasm, rather than its nuclear content. They are *somatic* males and produce sperm, but the nuclear content of those sperms has a female influence on the sex of offspring, since from all *fertilized* eggs females develop. This male somatic influence of the egg cytoplasm is accordingly contrary in nature to the nuclear influence of the egg, and it is strong enough to more than offset that influence when the egg remains unfertilized, so that a male individual results. But if the egg is fertilized and a second nuclear influence, that of a sperm, is added to the likewise female influence of the egg nucleus itself, then their combined female tendency overbalances that of the egg cytoplasm, and a female is produced.

We must then, in the case of the hymenoptera, recognize the *cytoplasm of the egg* as an agency in somatic sex determination equally important with the sex genes carried in chromosomes.

This is theoretically important, since it shows that cytoplasm as well as chromosomes may function in heredity, contrary to the commonly accepted idea that all inheritance is through the chromosomes of the cell nucleus. That non-chromosomal heredity is a reality is shown also by the work of Little and his associates on the inheritance of susceptibility to cancer in mice, in which maternal influence is much greater than paternal influence, being rated by the authors as more than six times more influential; also by the demonstration in mice and rabbits in my laboratory that the influence of the mother is greater than that of the father on the body size of offspring, a finding which is supported by a like result obtained by two other investigators

in species crosses of amphibia differing in body size.

When we oldsters took the general biology course thirty or more years ago, there were several groups of animals and plants known to reproduce sexually and yet among which no somatic sex differentiation was known to occur, either among the parents or among the gametes which they produced. This made it all the more reckless for me to hazard a guess that all gametes uniting in pairs were of opposite sex, but ignorance and youth are always courageous, and, as it has turned out, subsequent investigation has greatly reduced the field in which sexual differentiation of gametes is unknown. I beg to call your attention to three significant discoveries in this field.

About the time that I was speculating on paper about sex, I had as a pupil in a general zoology course a graduate student from the laboratory of Professor Roland Thaxter. He was working under Thaxter's direction on the sexual reproduction of the bread moulds and made the important discovery that they are sexually dimorphic. The bread moulds have long been a classic laboratory example in which to demonstrate the formation of zygospores, *i.e.*, sexually produced spores, by union of the tips of the thread-like hyphae of the fungus. But it was known to be tricky material. It was easy enough to grow the mould on stale bread kept moist and warm and to obtain quantities of the asexual spores, those which do not involve sexual reproduction; but to obtain zygospores was a gamble to the laboratory instructor. Sometimes they would form and sometimes they could not be induced to form in a laboratory culture. Blakeslee, Thaxter's pupil, better known now for his study of Jimson weeds, discovered why this is so. Mould plants grown from single spores are of two sorts, which Blakeslee designated + and – respectively, being uncertain which to call male and which female, or indeed whether their differentiation was of this nature. Zygospores form only when hyphae of a + plant come in contact with those of a – plant. Plus plants grown on agar plates side by side with plus plants, or minus plants grown side by side with minus ones, form no zygospores, but the moment a plus and a minus are grown side by side, abundant zygospores are formed, where their hyphae come in contact. Blakeslee showed that a similar sexual differentiation into plus and minus strains occurs in numerous other species and genera of fungi and that the plus strain is frequently more vigorous in growth and so possibly might with propriety be designated female. A plus plant will not give a sexual reaction (attempted formation of zygospores) if grown beside plus plants of any other species, but it will often give a sexual reaction to minus plants of other species or genera. This shows that a qualitatively similar differentiation as to sex occurs in many of the group, if not in all.

Another classic example among the lower plants of sexual reproduction without the occurrence of morphological differentiation in the uniting gametes was found among the algae, such as sea-lettuce, which reproduces by the formation of swarm spores, one-celled green flagellate individuals which frequently unite in pairs, though union is not obligatory to their continued life and growth. Hartmann has shown that union occurs only between pairs which are physiologically different. Like Blakeslee, in the case of the moulds, he recognizes among the algae plus and minus individuals. He also recognizes different degrees of plusness and minusness, which may be distinguished as strong pluses and weak pluses, strong minuses and weak minuses. Any plus will unite with any minus individual, whether weak or strong. Further, union may occur between a strong plus and a weak plus, or between a strong minus and a weak minus, if the difference between them is sufficiently great. This

leads him to formulate a principle of *relative sexuality*.

If Hartmann is right in this, we must accordingly extend our description of sex differentiation to include quantitative as well as qualitative differences in sex reaction. A sex union will occur only between gametes which are *different* in sex reaction, one female and one male, or one plus and one minus, or one with an *excess* of plusness or minusness as compared with the other.

Another of the troublesome problems of the general biology teacher, how to get paramecium to conjugate for class study, has recently been solved, with the discovery by Sonneborn, of Johns Hopkins University, that conjugation will occur only between individuals which are of different sex. As the two sexes are indistinguishable in appearance, Sonneborn calls them Sex I and Sex II, rather than plus and minus or female and male, as one might equally well do.

The sexual differentiation in this case is dependent on the character of the macronucleus, which must be qualitatively different in each member of a conjugating pair. In asexual reproduction the sex of a paramecium individual and that of all the offspring remains unchanged (since in this process the same macronucleus persists), but after conjugation (or endomixis) it is wholly a matter of chance whether the individual has the same or a different sex reaction as it previously had. This is because at such times the old macronucleus disintegrates and a new one is regenerated from a micronucleus, and this micronucleus may or may not be of the same sex as the old macronucleus.

In the conjugation of paramecium, as in the fertilization of a sea-urchin egg, we can recognize a two-fold sex differentiation. First there is a somatic differentiation of the conjugating individuals as of sex I or sex II, which attracts them to each other and occasions pairing. Before pairing any sex I individual will attract any sex II individual, but not afterward. Its differential charge has then ceased to exist. But there remains an attraction between gametic micronuclei developed in the conjugating pair. A "migratory" micronucleus leaves the body of each conjugant and passes over into the body of the other conjugant to unite with a "stationary" nucleus there, which is probably of different sex, since it attracts and fuses with the migratory nucleus, after which the attracting property ceases to exist.

Conclusion

We are now ready to formulate a tentative theory of sex. Sex is primarily a differentiation, electrical or otherwise, of the soma (cytoplasm) of gametes, which brings those of opposite character together and causes them to fuse. It is in agreement with and may be regarded as dependent upon the somatic character of the parent, being male when the parent is male, female when the parent is female.

The somatic character of a parent is determined as a feature of the Mendelian inheritance of sex-genes borne in the gametes which unite to produce that parent. In one system of sex determination found in flies and mammals maleness is dominant in heterozygous unions of sex genes, but in another system found in birds and moths femaleness is dominant in heterozygous unions.

An exception must be noted, in the case of hymenoptera, to the rule that sex genes borne in chromosomes (apart from hormone influence) exclusively determine the sex character of an individual. Male somatic differentiation of the unfertilized egg must in this case be ascribed to a male influence of the egg cytoplasm, which is strong enough to overbalance the female influence of a single set of chromosomes, but is inferior to the female influence of *two* sets of chromosomes exerted in the fertilized egg, even though one such set was brought to the egg in the sperm, the somatic character of which is male, though its sex-gene content is female.

THE PRESENT STATUS OF ESTHETIC MEASURE[1]

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FROM a certain point of view individual experience may be regarded as a succession of esthetic adventures. For example, in wandering upon an Alpine mountain side one may enjoy various flowers, occasionally noticing a single flower or cluster of flowers which is felt to be unusually lovely. And in all the occurrences of ordinary life there are many similar judgments of relative esthetic values. On considering this phase of our experience in more detail we become aware of the fact that what is appreciated is often some kind of unifying symmetry or other integrating type of order. Indeed it was long ago concluded that esthetic quality is correlated with unity-in-multiplicity. Yet this conclusion has to be carefully safeguarded in various ways; thus the mere repetition of an agreeable symmetry soon becomes wearisome if not actually unpleasant.

When I first became interested in esthetic questions nearly thirty-five years ago, I found that no thoroughgoing formalistic theory had ever been formulated. I felt that at the very least it should be possible to assess more adequately the rôle of the formal elements of order in determining the esthetic quality of an object. My own theory was finally embodied in a book "Aesthetic Measure," published in 1933. The general program called in the first place for the enumeration and quantitative estimate of the elements of order making for unity in the object. The arithmetic sum of these elements was designated as the order O. In the second place it was necessary to measure similarly the multiplicity or complexity C of the object. The ratio of O to C was called the esthetic measure M of the object, being associated with its degree of unity-in-multiplicity. It was hoped that in each of the specific classes of objects considered the esthetic measure M would roughly correspond to the esthetic value.

Of course the success of such a detailed program depended not only upon the selection of the really important elements of order in the object, but also upon a reasonable determination of its complexity. Psychologically speaking, the order O measured the favorable esthetic attitudes induced by the perception of the index of the number of items requiring consideration in the field of attention.

I realized fully that this was a most daring project, and also that there would necessarily be omissions and other imperfections in its execution even if it were fundamentally sound. Yet it seemed to me to be a step which was absolutely necessary if the subject of analytic esthetics were to be advanced. Perhaps as Dr. C. C. Pratt has said,[2] it was a "step which all formalistic theories have needed to take, but apparently have not been bold enough to attempt, ever since the days of Plato." I shall feel very well satisfied if my work serves to point the way to a more satisfactory formalistic theory, or even if it only leads to a better understanding of the formal factors in esthetic judgment.

[1] Address before the American Science Teachers' Association at Indianapolis, December 30, 1937.

[2] See his article "Structural *vs.* Expressive Form in Music," *Jour. Psychol.*, 1938.

Having thus set down an empirical theory which was susceptible of verification or disproof, I awaited with particular interest the experimental testing of its validity. Recently a very significant article by Drs. J. G. Beebe-Center and C. C. Pratt[3] has appeared which contains the results of experiments bearing on my theory and involving most of the types of objects which I had considered. My purpose here will be to indicate briefly the kind of analysis of esthetic measure which I had given in these cases, as well as the general conclusions of Beebe-Center and Pratt, and to add some comments and suggestions.

Before going further, one or two preliminary remarks concerning the concept of esthetic measure need to be made. In the first place, although the basic formula $M = O/C$ may be regarded as qualitatively valid always, its quantitative application must be limited to what I have called formal elements of order, in contradistinction to connotative elements of order. This refers to the well-known difference between form and meaning. For example, no formal theory such as that of esthetic measure can ever hope to deal with the elusive meanings which are present in a poem, although it might evaluate the musical quality. In the second place, it is precisely the elements of order whose presence we feel but have not explicitly analyzed that please us most by virtue of a certain occult quality. This does not mean, however, that if a profusion of formal elements occurs which we could analyze individually if time permitted, there would not be a similar effect. In the third place, the theory of esthetic measure in no way tends to a mechanical view of art. For instance, a definite scheme of measuring the formal beauty of a melody would not enable us to find sequences of notes which are remarkable in this respect. After all there would be the same difference as between discovering a diamond and assessing its value.

The first and simplest class of objects which I considered was that of polygonal forms, typified by tiles set in vertical position. The positive elements of order in O which I named were those of vertical symmetry, equilibrium, rotational symmetry and relation to a horizontal-vertical network. There were also certain negative elements of order which operated to diminish the esthetic effectiveness. The complexity C was taken to be measured by the number of lines containing all the sides of the polygon. For example, in the case of a square the complexity C would be four, and in the case of a Greek cross it would be eight. By way of verification of the theory I selected ninety polygons of varied form and arranged them according to the esthetic measures M theoretically assigned to them. As far as I could tell there was in general a decrease in esthetic quality along with the diminution in esthetic measure. This judgment was borne out by a crude experiment made by me while teaching one summer at Columbia University. Before informing the students in a large class about my theory I asked them all to arrange the polygons according to their own personal preferences. The arrangements showed general agreement with the theoretical predictions. It should be added that I instructed the students to disregard as far as they could irrelevant connotations such as, for instance, the religious connotation of the Greek cross. These connotations were of several types.

The first part of the study of Drs. Beebe-Center and Pratt dealt with polygonal form and was based on the judgment of six lay observers concerning forty-five

[3] "A Test of Birkhoff's Asethetic Measure," *Jour. Gen. Psychol.*, 1937. Messrs. F. W. Swift, A. J. Schnittkind, H. W. Miller and Egbert Fischer collaborated in the experimental work carried out in this paper.

of the ninety polygons. The theoretic result according to the formula was treated as if due to a particular seventh observer B. It was found that there was a great deal of divergence in the individual judgments as to the relative esthetic merits of the forty-five polygonal forms, but on the whole the results were conformable to the theory, as will be shown by the following quotations. Of the six lay observers "two observers agree better with the rest of the observers than did the formula and four less well." The conclusion was that my "formula for polygons has a considerable degree of validity." It was found, curiously enough, that the results for groups of students of psychology or of art diverged far more within the group than did those obtained from lay observers.

A partial explanation of a lack of agreement between theory and experiment for some of the polygons may well lie in the following fact: There are certain polygons which so readily suggest other polygons that thereby a purely geometric association is established. For example, the six-pointed star will certainly suggest two related equilateral triangles. To offset this I had relied upon the specific use of actual tiles in embodying the various polygons, for I thought that in this way the consideration of further polygonal forms could be largely done away with. But I believe to-day that it is impossible to discount this particular type of suggestion, so that certain polygons must be ranked higher than the theory indicated. To take proper account of this esthetic effect I propose to introduce a further element of order P in the formula for polygonal form,

$$M = \frac{O}{C} = \frac{V + E + R + P - F}{C},$$

as follows:

In case the given polygon fully outlines the vertices of further convex polygons possessing exactly the same symmetries as the given polygon, P is R; otherwise P is O.

This asserts precisely that the presence of such outlined polygons doubles the effect of rotational symmetry. Only eight of the ninety polygons have their esthetic measures modified by this change, namely, Nos. 13, 23, 25, 29, 50, 51, 65 and 69 of my list. The rating of the six-pointed star No. 6 is unaffected since the outlined equilateral triangles do not enjoy the six-fold symmetry of the star.

It was just this kind of change which I foresaw that the theory of esthetic measure would need to undergo in its special applications. I wish to express thanks to Dr. Beebe-Center in this connection, since the above suggestion arose in my mind during stimulating talks with him about the experiments on polygonal form.

The second class of objects which I considered was that of simple vase forms. Here there was an obvious division of esthetic factors into three types: those related to utilitarian requirements, to regularity of outline and to geometrical relations of the contour seen in perspective. In my theory I devoted attention mainly to the third type of factor. As far as I could determine by constructing vase forms and by examining the photographs of certain ancient Chinese vases, the theory which I proposed was borne out to a reasonable extent. Nevertheless, I felt and still feel that the true elements of order are very difficult to determine. Fifteen plane figures representing the contours of vases were selected and rated by various observers in the experiments of Beebe-Center and Pratt. The general conclusion was of the same character as in the case of polygons, namely, that for the naïve observer the ". . . formula is as good a test of aesthetic value as is the average observer."

In this case, however, the judgments of a group of seven students and instructors

of fine arts which were consistent among themselves diverged widely from the predictions of the formula. Hence Beebe-Center and Pratt concluded that "the formula applied to vases is a good measure of aesthetic value as judged by laymen, but that it is a poor measure of aesthetic value as judged by sophisticated art students." It is conceivable of course that the group of seven students and instructors of fine arts had become so accustomed to a few accepted vase forms such as those embodied in Greek vases as to bring about a connotation operating against the appreciation of the wide variety of forms found in Chinese pottery.

To my way of thinking, the visual field of geometric form so far considered is much less likely to be crucial for the theory of esthetic measure than the auditory field connected with music. In his paper already referred to Dr. C. C. Pratt distinguishes between two kinds of form in music: structural form and expressive form. According to him expressive form for the individual results from the use of a "tonal design which resembles very closely the internal pattern of his own affective state." I should myself consider it as probable that such expressive form is due to an occult similarity to emotional utterances of the human voice or other expressive sounds. Of course expressive form would fall in the connotative realm which I excluded permanently from consideration at the outset as beyond the scope of any formalistic theory. In the auditory field I undertook to discuss the esthetic measure of single diatonic chords, of the sequences of two chords treated in harmony, of simple melody, and finally of the musical quality in poetry.

In the case of the chords I selected certain obvious elements of order, based upon a genetic study of the well-known nature of these chords. The general condition for a good diatonic chord consists in its degree of parallelism to an ordinary musical tone such as is found for instance in the human voice. The esthetic measure which I gave explained adequately the usual rules of harmony governing our preferences among the various diatonic chords.

In attempting the analysis of the esthetic quality of sequences of two diatonic chords which forms the basis of classical harmony, I began by taking the order O of a chordal sequence to be measured by the sums of the esthetic measures of the individual chords and of a certain transition value which was determined by explicit rules. Thus, if one passed from a dissonant chord to a consonant chord through a resolution, the transitional element of resolution was regarded as present. For the testing of these rules I was very fortunate in having at hand a classification of all possible sequences of such chords in fundamental position or in first inversion, which had been given by E. Prout, a widely known expositor of classical harmony. He had classified all these sequences into three groups, as good, possible or bad. There was as complete agreement as could possibly be desired between Prout's tables for 168 types of chordal sequences and the theory of esthetic measure.

When it came to the experimental study of such chordal sequences by Drs. Beebe-Center and Pratt, the inter-correlation on the basis of ten selected chordal sequences was found to be very low indeed, although the final conclusion was again of a similar character, namely, that my "formula for diatonic harmony is as good a test of aesthetic value in this field as is the judgment of an average observer." In their opinion and in my own, the low correlations have to do with the fact "that the observers frequently heard the chordal sequences as figures upon uncontrolled tonal background—images." For "it is almost impossible

for a person with any musical experience at all to hear a sequence of two chords completely detached from an imaged key-setting." From this point of view the ratings of Prout might then indicate the relative richness of various chordal sequences in power of entering into combination. But this would seem to me to be very strong evidence indeed that the factors which I isolated are substantially those which are esthetically effective.

In the case of melody the results were more favorable. Five unharmonized simple melodies were invented and their esthetic measures calculated. All five were of the same length and rhythm. None of them were established melodies, but the first was an inversion of the famous Chorale in the last movement of Beethoven's Ninth Symphony. Of the four others the relative ranking given by my theory was exactly the same as the average ranking of nineteen students of music. These same students, however, gave the inversion of the Beethoven theme third position instead of the first position which it should have had according to my theory and would doubtless have received if it had not been inverted.

A partial explanation of this divergence from the theory may be that these musical students recognized the inferiority of the inversion which violated the spirit if not the letter of a rule which I had formulated: "It must not be possible to increase the tonal order O by alteration within a short succession of notes (say not more than four), together with corresponding alterations in its repetitions, transpositions and inversions." In fact the original Beethoven chorals is essentially derived by such an inversion, and has a higher order O.

It is almost certain, however, that this explanation is not sufficient. Drs. Beebe-Center and Pratt conclude indeed that for melody the formula works "reasonably well," but that the average judgment appeared to be "more univocally determined by some factor as yet not properly taken account of in the formula of aesthetic measure of melodic value."

What then is the omitted factor? Before giving the probable answer to this question, it is of interest to observe that it was precisely in the process of constructing sequences with high formal rating but of inferior melodic character that I had previously determined certain factors which were overlooked in first attempts to set up a theory. In this work I was aided by an exceptionally intelligent and musically trained student who spent several months trying to "break" the theory, as I had instructed him to. At the end we both came to the realization that it was getting very difficult indeed to set up an unmelodic sequence of notes with high rating and quite impossible to find a familiar melody with a low rating.

Now the inversion of the Beethoven chorale referred to above proves on further inspection to have a serious formal flaw, not forbidden by the seven "further conditions of satisfactory form" which I had enumerated but which should be excluded by the first condition referring to "regularity of pattern." Let me state this omitted requirement:

The tonic note, in its first appearance (not imbedded *within* a subdominant or submediant sequence) must either be the first or last note of the melody, or part of a tonic sequence at the commencement of the melody, or an accented note, or an unaccented note within a tonic sequence. Otherwise the tonic center is not felt to be properly announced. In glancing over about one hundred well-known simple diatonic melodies in four-part time, I have not discovered any exceptions to this requirement of satisfactory form.

In the original Beethoven chorale which starts with the four measures[4]

4 In this notation 1 designates the tonic, 2 the supertonic, etc.

| 3345 | 5432 | 1123 | 3222 |,

the tonic center is appropriately introduced at the first accented note of the third measure. But in the inversion under consideration,

| 3321 | 1234 | 5543 | 3422 |,

the tonic makes its appearance at the fourth unaccented note of the first measure and yet is not part of a tonic start or imbedded in a tonic, subdominant or submediant sequence. Hence the tonic center is improberly announced, and even the untutored ear feels that something is wrong, without knowing what it is. If the inversion is modified in the first measure to any of the manifold alternative forms complying with the rule it will be found that the particular kind of disagreeableness in question disappears. Unfortunately, the melodic sequence loses in other elements of order thereby; in particular the third measure is no longer an exact transposition of the first.

Thus this experimental melody serves to bring to light a supplement to my condition for regularity of pattern—the omitted factor.

On inquiry of Professor W. H. Piston he kindly informs me that, so far as he knows, no similar musical requirement has been stated anywhere, although he can think of no obvious exceptions to it in relevant musical works. Unless I am badly mistaken there are brought to light in my theory of esthetic measure many similar instances of 'unwritten' formal laws in esthetic fields. And it is a considerable part of my claim that the totality of such laws, explicit and implicit, determines the esthetic judgment of form.

One further remark may be made here. As originally brought to me by Mr. Fischer the proposed melodic sequence was an exact inversion of the Beethoven chorale:

| 3321 | 1234 | 5543 | 3444 |.

But I pointed out that this would not do because it violated the condition for regularity of pattern in its lack of cadences. For this reason it was modified by Mr. Fischer as indicated above, to the definite improvement of its melodic quality. I did not go further into the matter at that time, since the main object of the experiments was to test the theory of esthetic measure exactly as I had formulated it.

It was in the application to musical quality in poetry, where first experiments appeared to indicate a definite failure of the theory, that the clearest confirmation of its general validity was found. In my own study I had fixed upon the obvious elements of alliteration and assonance, of musical vowels and of rhyme, as giving the principal elements of order. On the other hand, I had measured the complexity by the number of simple sounds. With this basis I analyzed a number of poetic passages and found relative esthetic measures which agreed with my own judgment and that of several persons whom I consulted. In the preliminary experiments with poetry made by Drs. Beebe-Center and Pratt there was found at first an almost complete lack of correlation between the judgments of the various observers. It was still true, however, that my formula agreed "better with the group as a whole than any member of the group," even if the agreement was low. Here the possibility was indicated that there was a great interference of poetic meaning with the impartial judgment of the intrinsic musical quality of the lines.

On this account seven nonsense lines were constructed having esthetic measures which varied from 1.16 down to .40 according to the formula. These lines were read to five persons individually. The first line with highest rating according to the theory was:

Salanta moanralume oarimely loase;

and the one with lowest rating was

Bered ak filner dinstem jeebenot.

The results obtained showed that the "formula represents empirical aesthetic value as well as it possibly could with the experimental technique." In fact, the highest average correlation of any observer with the others was .75, which was just the same as that of the formula. This conclusion was in agreement with results which had been previously reported by Dr. R. C. Davis,[5] although Davis's results concerning polygonal forms were apparently adverse to the theory of esthetic measure.

Thus it appears from the various experimental findings of Beebe-Center and Pratt that the specific formulas which I had constructed more or less empirically "are valid as first approximations to quantitative rankings of aesthetic value." Naturally a great deal of further work will have to be made before the exact extent of their validity is known. More elaborate experiments are now being made under the direction of Dr. Beebe-Center, in which it is hoped that the method of factor analysis will throw light upon further experimental data.

In conclusion I would like to refer to an interesting suggestion of Dr. Beebe-Center's that there may be two or more kinds of observers: as, for instance, the lay observer of objective type who unconsciously takes account of utilitarian qualities possessed by the object; and the much rarer, esthetically minded observer, who is influenced by accidental and variable connotations. Dr. Beebe-Center thinks it is possible that "aesthetic measure" may be more representative of the objectively minded observer than of one of the second type, to whom indeed no formalistic theory would be likely to apply with any degree of success. I must confess personally to considerable distrust of the latter, *quā* observer.

[5] "An Evaluation and Test of Birkhoff's Aesthetic Measure Formula," *Jour. Gen. Psych.*, 1936.

FUNDAMENTAL RESEARCH AND ITS HUMAN VALUE[1]

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THE keynote of this congress is the application of science to human needs. To gauge the power of science to meet present and future needs, let us examine the methods by which science has been used to solve problems of the past.

MODERN LIFE DEPENDENT ON SCIENCE

Modern life is absolutely dependent on applications of science. Consider, for example, the conditions that would arise in any large city if we had to return to the systems that were in use a century ago for sanitation, for water supply and for the distribution and preservation of food! The lives that have been saved through the work of Pasteur, and of those who have applied his discoveries, must surely now be counted by the tens or even hundreds of millions. Think of the reduction of human suffering by anesthetics, by surgery, by the elimination of diseases such as plague, yellow fever, smallpox, typhoid, malaria and tuberculosis. The steamship, railroad, automobile and now the airplane provide transportation indispensable to us. Electric power and light add to the comfort and efficiency of nearly every one in many countries. Consider also the telegraph, telephone and radio; cement, new metals and alloys, plastics, oil as fuel, etc.

The modern increased standard of living has depended not only upon such things as these, but upon labor-saving devices and methods which have resulted from the application of science. Only by producing vastly more than our forefathers has it been possible for us to consume more.

Another thing of perhaps greater importance that science has done has been to give mankind a new outlook on life. The theory of evolution has done much to set us mentally free. Enough of the scientific attitude has permeated the masses of mankind to eliminate many superstitions that caused much suffering through fears that have now been abolished.

All these changes that have resulted from the application of science have led in recent years to perhaps the greatest revolution in the history of mankind. The rapidity of these changes seems to be continually accelerating. Judging from the volume of scientific publications in the last thirty years there seems to be an increase of about 6 per cent. per year in scientific activity, or a doubling every eleven years.

Of course, such a rapid change has not taken place without bringing many new and serious problems. Much of our present economic maladjustment is due to a failure of our social organization to keep pace with the changes brought about by scientific progress.

EARLY PROGRESS MADE BY INVENTORS AND ENGINEERS

Until the beginning of the present century, applications of science had almost always been made by inventors and engineers who had utilized the stock of scientific knowledge available to them and who did not themselves contribute to

[1] Delivered by the author as a paper before the seventeenth Congress of Applied Chemistry at Paris, September 30, 1937, and printed in the December number of *Chimie et Industrie* with the title "La recherche scientifique pure et son importance au point de vue humain."

fundamental science. Pure science was mainly the outgrowth of work carried on in universities by those who were not primarily interested in the applications. Newton, the great French mathematicians and physicists Laplace, Ampere, Poisson, the chemical pioneer Lavoisier, the great English scientists Faraday and Maxwell, are names selected at random of those who laid the foundations for present science. Engineers and inventors, men like Edison, Elihu Thomson, Marconi and Bessemer, have applied science to meet human needs, but not many of them made great contributions to science itself. Pasteur is perhaps the most important exception. He was one of the greatest of scientists, and at the same time he made applications of science having the utmost direct value to mankind.

Establishment of Industrial Research Laboratories

Beginning about 1900, many industries established research laboratories whose object was primarily to apply existing scientific knowledge to the solution of industrial problems. Only a small fraction of this total knowledge had received industrial application, and it must have seemed to the leaders of industry as though the supply of available unused knowledge was almost inexhaustible. The industries felt no need or obligation either to contribute to or to extend the fundamental knowledge; it was only necessary to develop the applications to their particular needs. The age, after all, was one of unscrupulous exploitation of natural resources.

The success of industrial laboratories has been so great that in 1934 there were said to be 1,200 industrial research laboratories, employing about 30,000 people, in the United States alone. Undoubtedly the contributions of the industrial laboratories have now become more important than those of individual inventors and engineers.

In the vast majority of cases the work done in these industrial laboratories is directed toward specific ends; that is, it is aimed to solve problems which are known to exist within the industry.

In the past, however, a great many problems have been solved and have led to great benefits to mankind where a few years previously it was not even suspected that there was a problem to be solved. For example, there was no recognized need for the telephone or phonograph, nor for radio broadcasting until these improvements were already developed. A good example, which has forced itself strikingly on my memory, is that students of Union College, Schenectady, were broadcasting phonograph records every Thursday evening for the amusement of their amateur listeners several years before any of the commercial broadcasting stations were inaugurated, and yet the officials of the General Electric Company, many of whom knew of this, did not realize that such broadcasts were of any value. In other words, many great and important inventions or discoveries need to be thrust upon us before we can see their value. To expect that a director of an industrial laboratory will recognize the need for all the scientific developments which may be of importance to his industry is thus to expect him to be a superman.

Establishment of the General Electric Research Laboratory

In the year 1900, Mr. E. W. Rice, Jr., established within the General Electric Company at Schenectady an organized industrial research laboratory for the purpose of carrying on fundamental industrial research. It was planned that this laboratory should be devoted exclusively to original research or to the study of natural phenomena in search for new facts and principles. Mr. Rice was thus not content to draw from the storehouse of scientific knowledge built up in uni-

versities but wished to have a laboratory in which scientific progress could be accelerated and the frontiers of knowledge extended in directions which would be likely to prove useful to the industry. Such research can not usually be directed toward definite goals, for it involves unknown factors. Success in such research, if attained, is often reached by wholly unexpected methods, and the problem which is finally solved is not the problem which is foreseen.

As this laboratory developed it was soon recognized that it was not practicable nor desirable that such a laboratory should be engaged wholly in fundamental scientific research. It was found that at least 75 per cent. of the laboratory must be devoted to the development of the practical applications. It is stimulating to the men engaged in fundamental science to be in contact with those primarily interested in the practical applications. It is also important that the engineers in the organization should be in close contact with those having the broader scientific outlook.

Let me give an example of the useful interaction of the two groups of men. Let us suppose that through the discovery of a new scientific principle or fact the possibility of some new application is opened up. The men trained in pure science are usually not the men to make most rapid progress in the applications; on the other hand, it is not possible to turn the work over immediately to a separate engineering research laboratory. The growing idea, like a child, must not be weaned from its mother too soon. Before the continued development of the idea can be assured in the hands of an engineering staff, it is necessary for a relatively large amount of engineering research to be carried out by the originators of the idea or those closely associated with them, for only these have the necessary familiarity with the subject and the deep personal interest required for success.

If, however, some provision is not made for a separate engineering research department there is great danger that the engineering research may grow to such proportions as to undermine the spirit of fundamental research which should dominate the research laboratory if its proper functions are to survive. In the General Electric Company we have been fortunate in having several such engineering departments which are capable of taking over any problem from the research laboratory as soon as its ultimate success seems assured.

Personal Experiences in Research Work

I will give you some examples from my own personal experience to illustrate how fundamental scientific work undertaken without definite applications in view can result in discoveries that are of direct benefit to mankind. I want to show you how, in these cases at least, the practical result could hardly have been reached in a laboratory in which the workers were assigned definite work directed towards a goal. There was no one who had the vision to see the goal until we had nearly reached it.

When I started to work in our research laboratory, Dr. Whitney, who was then director, instead of assigning me to a definite problem, suggested that I spend several days in the various rooms of the laboratory becoming familiar with the work that was being done by the different men. He asked me to let him know what I found of most interest as a problem to work on.

I was particularly interested in the work that was going on in the laboratory with tungsten-filament lamps of the high-vacuum type. Much work had shown that the higher the vacuum the better was the lamp—that is, the less rapidly the bulb blackened. What interested me most, however, were the wonderful possibilities opened up to the scientist by having a material like tungsten, which could be heated to temperatures over 3400 C. If residual gases produced

harmful effects in a lamp, it seemed to me that it was a fascinating field for investigation to study the effects produced by each different gas separately introduced into the bulb. This work was not undertaken with a definite idea that it would lead to an improvement in the lamp; it was merely done to satisfy my own curiosity as to the interactions between gases at low pressures with filaments at high temperatures, a field of study which, I believe, never had been undertaken before. From Dr. Whitney's point of view it was a useful line of research for the General Electric Company because it would give us increased knowledge of the type of phenomena that are presumably occurring in lamps. The whole consensus of opinion in the laboratory, however, was that the direction that should be followed in seeking to improve the lamp was to obtain a far better vacuum than had previously been possible.

I worked for about three years studying these chemical reactions at low pressures with filaments at high temperatures, and published several scientific papers giving the results of this work. I was particularly interested in the results obtained by introducing hydrogen into the lamp, for this gas caused a very great heat loss from the filament. I was able to show that this was caused by the dissociation of hydrogen molecules into atoms. In order to make sure of the correctness of this explanation, I was led to experiment with nitrogen and with mercury vapor over a wide range of temperatures and pressures up to and including atmospheric pressure. At this time no one in the laboratory had any idea that any benefits could result from such gases.

Gas-filled Lamps

To be able to measure quantitatively the degree of dissociation, I needed to know how much heat was carried away from the filament by conduction and convection of heat by the gas. To get at the scientific facts underlying this loss of heat, I made experiments with filaments of various sizes and found the rather surprising result that a tenfold increase in the diameter of the filament in the case of a gas at atmospheric pressure caused only a relatively slight increase in the heat that was carried away by the gas.

In working with nitrogen, I found that the nitrogen had a peculiar tendency to disappear, and was able to prove that this was due to a chemical reaction by which each tungsten atom which evaporated from the filament combined with nitrogen to form a compound WN_2. In order to study this reaction I needed to determine the rate of loss of weight of tungsten filaments at different temperatures. I found that this loss of weight was due to evaporation, and not, as had been previously considered, to an effect of electric discharges. When working with nitrogen at atmospheric pressure, the rate of evaporation was decreased about a hundredfold because of the return of the tungsten atoms to the filament after they collided with nitrogen molecules in the gas.

I had noticed that with nitrogen at atmospheric pressure it was possible to maintain a filament at a temperature close to the melting point for a far longer time than if the filament were in a vacuum. I knew, however, that this increased life was more than compensated for by the increased loss of heat caused by the nitrogen. However, the laws of heat conduction which I had discovered indicated that if we used filaments of very large diameter carrying about 20 amp of current, the effect of the heat loss would not be so serious. This suggested the possibility of constructing lamps of high efficiency with nitrogen at atmospheric pressure by using filaments of very large diameter. This led to the construction of what was known as the half-watt lamp. Within a few months, improvements were made by substituting a coil, so that the effect of a large diameter filament could be obtained by a filament taking rela-

tively small currents and by the substitution of argon for nitrogen.

I want to call your attention particularly to the fact that there were many separate lines of pure scientific work which contributed to this successful result. There was nothing from the prior knowledge that suggested that any benefit would result from the addition of gas to the lamp; in fact, there was no lamp made in 1911 which would have been given an improved life or efficiency by the introduction of nitrogen. It required the construction of an entirely new type of lamp based on new scientific principles before this benefit could be obtained.

As soon as we received positive indications that an improved efficiency of the lamp would be possible through the use of argon and nitrogen, a large group of men in the laboratory worked on the development of this type of lamp. It took about six months of intensive work on the part of about twenty-five men before their results could be turned over to the development laboratories of the incandescent lamp factories, and it was about a year before these lamps were ready for manufacture.

Study of Thermionic Emission

As soon as this group started working on this problem, I began to devote my attention almost wholly to a study of electric discharges in lamps containing gases at very low pressures. With the high degree of vacuum which was used in ordinary lamps at that time it was found that the electric currents that could flow across the space between one end of the filament and the other, even with voltages of over 100 volts, were only a very few milliamperes. This fact seemed very peculiar to me, for the work of Richardson and others had indicated that at temperatures as high as those used in the tungsten-filament lamp, currents of many amperes should flow across the space. In other words, according to the then-accepted theory of the electron emission from hot filaments, a serious difficulty should have been encountered in the construction of tungsten-filament lamps. The fact that we did not meet any such difficulty therefore seemed to me a peculiar fact that should be investigated.

Now, in an industrial laboratory which is devoted to the solution of specific problems, it would not be reasonable to undertake an investigation to find out why no difficulty was found in the construction of lamps; there was no problem to be solved and therefore no need for any work in this field. I was only interested, however, in a thorough understanding of all the phenomena taking place in lamps, so I began to make a detailed study of the laws that govern the flow of current between tungsten filament in high vacuum. A few days of work led to the discovery of a new effect known as the space-charge effect. The electrons that escape from the hot filament require a definite time to cross the space to the positively charged end of the filament, and while these electrons are crossing the space they are repelling those that are leaving the filament behind them, therefore there is a definite limit to the current that can flow with a given impressed voltage. If a very small amount of gas is present, positive ions are formed which neutralize the effect of the negative charges on the electrons and thus permit large currents to flow. This explained the arcing of lamps that occurred with the presence of gas at pressures as low as 1/1000 of a millimeter.

I was able to work out mathematically the laws that govern the flow of current in high vacuum when this current is limited by the effect of space charge. In ordinary incandescent lamps this effect would limit the current to a few milliamperes, but by special construction using electrodes very close together and using much higher voltages, as I was able to see from this theory, it should be possible to obtain large currents in very high vacuum and at very high voltages.

Dr. Coolidge was then working on the use of tungsten electrodes for x-ray tubes

of the usual type which required the presence of gas. The new theory of electron space charge indicated that by using a vacuum several hundred times better and a hot tungsten filament as cathode, it should be possible to construct an x-ray tube of an entirely new type. These tubes were constructed and developed by Dr. Coolidge utilizing the new principles of high-vacuum discharge.

At that time, 1912, the deForest Audion had been used in detecting and amplifying radio signals. It was essential, however, in the operation of these tubes to use a certain amount of gas of about 0.005 mm pressure. In fact, the tubes were purposely made with a poor vacuum, for they failed to operate satisfactorily if the vacuum was too high. These Audions were always operated at about 20 to 25 volts on the plate and at a current of about 0.1 milliamp. They failed completely to work at higher voltages because of the wasting away of the filament and because of the development of "blue glow."

An understanding of the space-charge phenomena, however, gave an explanation of the fact that the Audion required the presence of gas for satisfactory operation. If the gas was pumped out of such a tube, the currents were too small to be effective, and the grid construction that had been used was no longer satisfactory. By using a vacuum hundreds or thousands of times better, we were soon able to operate at voltages of 10,000 volts and currents of 100 milliamp. This development, which took the Audion out of the field of a detecting tube for radio and made is application possible to the field of radio telephony and broadcasting, was thus the outgrowth of experiments undertaken solely to satisfy scientific curiosity. There was no one in the General Electric Company who was conscious of the need of a high-powered electron amplifier. However, once we were led to the construction of such a device we could immediately think of an enormous number of applications for it. This is another illustration of the fact that fundamental scientific research in an industrial laboratory is likely to lead to new and unforeseen applications.

The work on the heat losses from tungsten filaments in hydrogen had led to the discovery of atomic hydrogen and had given measures of the great amount of heat absorbed by the dissociation of the hydrogen. A few years later Professor R. W. Wood showed that when an electric discharge is passed through hydrogen at low pressures atomic hydrogen is formed, and that this can recombine on the surface of metal wires and cause them to be heated. My interest in this field and the work that I had previously done led me to see then that still greater results could be obtained by using hydrogen at atmospheric pressure with a high-current arc. I was thus led to develop the atomic hydrogen welding process for metals, which makes possible the welding of chromium steels and facilitates obtaining vacuum-tight welds. This proved to be an important factor in the fabrication of the sealed-in electric refrigerator unit, which helped to adapt electric refrigeration to domestic use.

About 1916 to satisfy a scientific curiosity and with no applications in view, I made some studies of the condensation of tungsten vapor on glass surfaces, and later continued this work with mercury and cadmium, and was able to show that certain ideas that had been proposed by others in regard to the nature of this condensation were incorrect. It had been maintained that at certain temperatures atoms of mercury and of cadmium could be reflected from a surface; that is, the molecules upon striking the surface would bounce off again. I showed that the phenomena could be better explained by assuming that the molecules or atoms on striking the surface always condensed, and that then, after a certain time interval depending on the temperature, they would evaporate off. This theory played an important part in the development of

theories of absorption of gases on surfaces. Shortly after this, Gaede described the construction of a mercury-vapor pump called the diffusion pump, which gave an extraordinarily high vacuum but was a pump of essentially low speed, the maximum speed being only about 80 cc per sec. This low speed resulted from the fact that the diffusion occurred through a narrow slit. Gaede pointed out that the slit could not be made wider without causing a lowering in the speed of the pump. From the work that I had done on the condensation of mercury vapor on glass, knowing that the molecules were not reflected, I was in a position to realize immediately on reading Gaede's article that the serious limitation in the speed due to the narrowness of the slit employed could be avoided by depending on condensation of the mercury on a cooled glass surface, involving a simple but novel design of the pump. This resulted in the construction of the condensation pump, which immediately increased the speed of the mercury-vapor pump from 80 to about 4,000 cc per second. Again you will notice that it was only investigations conducted for their pure scientific interest that led to the improvement in the pumps that I have described.

Monolayers and Multilayers

The work with tungsten filaments and gases done prior to 1915 had led me to recognize the importance of single layers of atoms on the surface of tungsten filaments in determining the properties of these filaments. For example, a single layer of oxygen atoms would decrease the electron emission of the tungsten by a factor of 10,000, whereas a single layer of thorium atoms would increase the emission 100,000-fold. I recognized that this powerful action of monolayers of atoms resulted from the very short ranges of the forces that act between atoms and molecules. This view led me to believe that on the surfaces of liquids single layers of molecules should also be important in determining such properties as surface tension. I was led to make investigations of films of oil on water, and showed that such substances as olive oil spread out on the surface of water to form a layer which is just one molecule thick. By measuring the area to which a given amount of oil would spread one can thus measure the dimensions of the molecules. These results were published about 1918. I did very little further work in this field until about 1931. In the meantime, however, others had undertaken work along these lines, and some of the interpretations of the experiments that had been made were, I believed, erroneous. I was therefore led to write a paper on the structure of monolayers of fatty acids on water in 1931. This aroused my interest anew in this field. Later my assistant, Dr. Katherine B. Blodgett, who was making studies of these films on water, found that under carefully controlled conditions, using salts of barium or calcium in the water, films of stearic acid could be built up on a glass or metal plate in successive layers by merely raising and lowering the plate through a water surface. We have been studying these multilayers for the last few years. They have led to results of considerable scientific interest. We find that by depositing several hundred layers, counting the layers as we deposit them, we can get optical effects such as interference colors which enable us to measure with great precision the dimensions of the molecules of many substances. It also serves as a means of measuring the absolute values of the wave-lengths of x-rays. Until recently, however, we have not seen how these results could be directly applied to human problems or to human needs.

Last December Dr. Dorothy Wrinch visited our laboratories and asked if we could apply the technique which we had developed in the study of multilayers of fatty substances to the study of proteins. After a few days of work, we found that we were able to build up multilayers of

any protein on metal plates and in that way we were able to study many new properties of these important substances. We found that if we take a strip of chromium-plated brass and build up on it 49 layers of barium stearate and examine it with the naked eye by monochromatic light from a sodium-vapor lamp there is a sharp minimum in the intensity of the reflected light at a definite angle of instance. If now the plate is immersed for a few seconds in water containing thorium nitrate and is then washed, the plate then becomes capable of taking up from a solution into which it is dipped certain substances such as proteins and many other bodies of biological interest. The plate can then be washed with water and dried and again examined with monochromatic light. Any increase of thickness due to the substance taken up from the solution, even if only of 2×10^{-8} cm, is readily visible to the naked eye.

We have thus evolved a method of rendering visible single layers of atoms or molecules. It is a quantitative method which enables us to make measurements of the diameters or sizes of molecules of many different substances. For example, if we dip the prepared plate into a solution of egg albumen we get an increase of thickness of 50×10^{-8} cm, whereas if we dip it into a dilute solution of another protein, the virus of the tobacco mosaic disease, which is known to be a protein having a very large molecular weight (17,000,000) there is an increase of 300×10^{-8} cm. Each different protein that we have tried gives its own characteristic thickness by a measurement which takes only a few minutes.

Furthermore, we find that the proteins thus taken up by the plate retain their biological activity. For example, the plate will take up a layer of diphtheria toxin, and then, although it will not take up any more toxin, it will take up the diphtheria antitoxin. It looks therefore as though this method of rendering these thin films visible should have great value as a biological tool; very likely it will find a place in the diagnosis of disease. It has the advantage that it makes possible the detection of extremely minute amounts of substances from very dilute solutions. By a modification of this technique, for example, we find that we can detect inorganic salts in water at concentrations as low as 10^{-9} molar, which is about 1 part in 10 billion parts of water. Thus these experiments with multilayers seem to open up several promising lines of research which may well have applications to human needs.

The examples that I have given you show that many radically new things for the home as well as elsewhere come from fundamental research and are not foreseen while the research is in progress. Such foreknowledge is impossible in many cases, for the research leads to new facts and a better understanding of fundamentals which makes the application possible.

I do not wish to leave the impression that all industrial research can profitably be of the fundamental type that I have outlined. It is usually the large industry which can best afford to undertake work of this kind. Wherever specific problems are definitely known to exist, it is of course logical to organize research work for the solution of these problems. If, however, in a large laboratory 10 or 20 per cent. of the men are given an almost free hand to follow up new and promising lines of pure scientific research, and, particularly, are encouraged to make a thorough scientific study of the nature of the phenomena involved in industrial processes, the industry may benefit from radically new developments which could not occur by any planning on the part of the directors of the laboratory.

RECENT ADVANCES IN THE THEORY OF FERROMAGNETISM

By Dr. RICHARD M. BOZORTH

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In the last five or ten years the theory of ferromagnetism has finally shown signs of maturity. For the first time a story can be told concerning the ultimate magnetic particle, the essential nature of the atom of a ferromagnetic substance, the kind of forces which determine the properties of magnetic crystals, the effect of strain on magnetic materials, and the manner in which these various phenomena combine to determine the properties of commercial materials. It is true that the story is largely qualitative, and that there are still many points that are uncertain or missing entirely, but nevertheless it is possible at least to discuss them.

The fundamental magnetic particle is the spinning electron. Although one might think that the orbital motions of the electrons in the atom would also contribute to ferromagnetism, since these give rise to magnetic moments, it has now been established that when the magnetization changes, it is only the direction or sense of the spin of certain of the electrons in the atom which changes—the orbital motions remain as before.

The electrons that are responsible for the magnetic properties of iron, cobalt, nickel and their alloys lie in a definite "shell" in the atom. As shown in Fig. 1, there are four shells or regions, more or less well defined, into which all the electrons circulating about the nuclei of these atoms may be divided when the atom is separated from its neighboring atoms, as it is, for example, in a gas. Some of these shells are subdivided as shown. When the atoms come closer together as they do in a solid, the fourth or outmost shell becomes disrupted, and the two electrons which comprised it wander from atom to atom and are the "free" electrons responsible for electrical conduction. The electrons in the outer part of the third shell are those responsible for the distinctive kind of magnetism found in iron, cobalt and nickel. Some of these electrons spin in one direction and some in the opposite, as indicated, so that their magnetic moments partially neutralize each other, and it is the excess of those spinning in one direction over those spinning in the other that causes each atom as a whole to behave as a small permanent magnet.

The well-established kinetic theory of matter tells us that if each atom were to act independently of its neighbors, the atoms would be vibrating and rotating with such strength that they could not be aligned even with the strongest field that can be produced in the laboratory. To explain the kind of magnetic properties found in iron, therefore, it is necessary that there be some force present which will make the magnetic moment of a group of neighboring atoms lie parallel to each other—the small atomic "permanent magnets" of each group must point in the same direction so as to provide a magnetic moment great enough to permit a realignment when subjected to external fields. Recently it has been shown by independent means that there is such a force in just those elements which are ferromagnetic, and it is from this force that the difference between magnetic and non-magnetic materials arises. The force is electrostatic in nature and is called

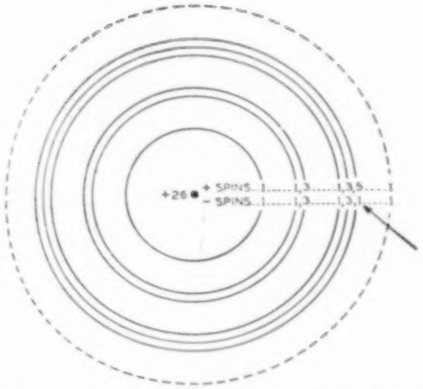


FIG. 1. ELECTRON SHELLS IN AN ATOM OF IRON. THE ARROW INDICATES THE SUB-SHELL THAT IS RESPONSIBLE FOR THE MAGNETIC PROPERTIES.

"interaction" by the atomic-structure experts, the wave mechanicians, who have shown its existence and calculated its order of magnitude. This force maintains small groups of atomic magnets parallel against the forces of thermal agitation, unless the material is heated so hot that the disordering action of the agitation becomes strong enough to overpower the forces of "interaction." When this occurs the material loses its ferromagnetism; in iron this happens at 770° C.

For some reason not at all understood at present, at ordinary temperatures the electrostatic forces of "interaction" maintain the elementary magnets parallel only over a limited volume of the specimen. This volume is of the order of 10^{-9} cubic centimeters, and contains a million billion atoms, but would be too small to be seen by the naked eye if it were isolated. Such volumes are said to be saturated because the atomic magnets are all pointing the same direction, and have been given the name *domains*. Thus a magnetic material at room temperature, before it has been magnetized by subjecting it to the influence of a magnetic field, is divided into a great many domains, each of which is magnetized to saturation in some direction generally different in neighboring domains. The net or vector sum of the magnetizations is thus zero, and externally the material appears to be unmagnetized but in reality the magnetization at any one point is very intense. When a magnetic field is applied by bringing a permanent magnet or a coil of wire carrying a current near the metal, the magnetization of the material as a whole is increased to a definite value. The mechanism by which this takes place is simply the change in direction of the magnetization of the domains. If we represent the magnetization at any point by a vector, the effect of the externally applied field is only to rotate the vector—to change its direction but not its magnitude.

Recently much has been learned about the magnetic properties of materials by a study of single crystals. Ordinary metals are composed of a great many crystals often too small to be seen easily by the naked eye. But in the last few years methods have been found to make large crystals of almost all the common metals, crystals as large as the more familiar ones of rock candy and even of quartz. Experiments on such crystals of iron show that they are much more easily magnetized in some directions than in others, and these directions are called "easy" and "hard" directions of magnetization.

This dependence of ease of magnetization on direction is illustrated in Fig. 2 for iron and nickel in relation to the positions of the atoms in the crystals. The circles represent the atoms which take up positions on an imaginary framework or lattice. Because of the smallness of atomic dimensions only a small fraction of the atoms in a crystal of ordinary size are shown, but the same pattern, the unit of which is outlined by solid lines, extends throughout the whole of the single crystal. The arrows indicate the directions of easy magnetization, which are different for the two materials as may be noticed.

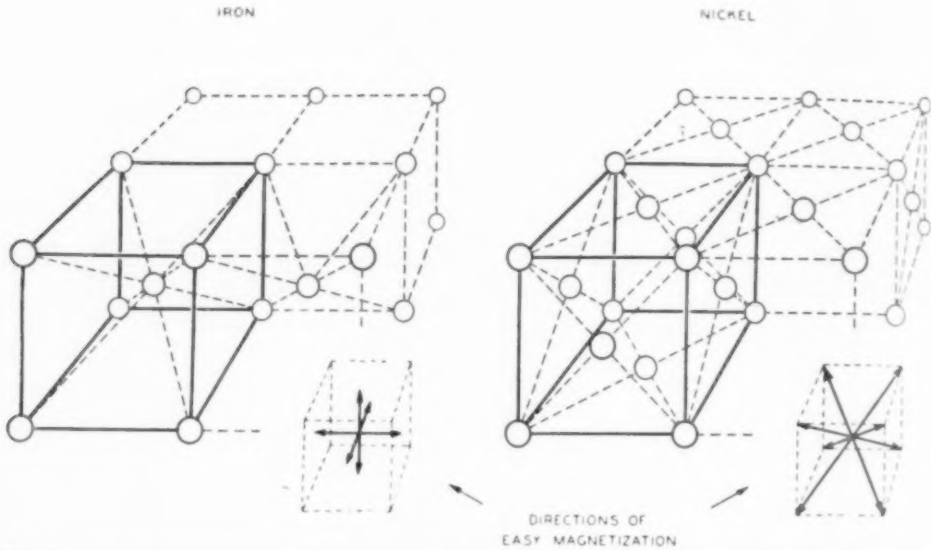


FIG. 2. THE POSITIONS OF THE ATOMS AND THE DIRECTIONS OF EASY MAGNETIZATION IN CRYSTALS OF IRON AND OF NICKEL.

In order to comprehend better the relative sizes of crystals, domains and atoms with which magnetic processes are concerned, it may be pointed out that a piece of ordinary iron a cubic centimeter in volume may contain about 10,000 single crystals, and that each crystal contains on the average 100,000 domains each with from 10^{14} to 10^{15} atoms.

It has been shown that the easy and hard directions of magnetization are due to the mutual magnetic forces between neighboring atoms. As far as the *electrostatic* forces of interaction are concerned, which cause neighboring atoms to be magnetized in the same direction as each other, any one direction in a crystal is as easy as another. The *magnetic* forces, however, are much stronger in some directions than in others, and it is these magnetic forces that determine in which particular direction the atomic magnets will point, and thus "select" the directions of easy magnetization in the crystal. The electrostatic forces are much stronger than the magnetic forces, but the latter alone are directional.

In a cubic crystal of iron the directions of easy magnetization are parallel to the cubic axes, that is, they are the six directions parallel to the edges of the cube which represents the structure. When such a magnetic material is unmagnetized, a portion of one of the crystals in it may be represented by the schematic Fig. 3(a). As shown, each of the domains, represented by the arrows, circles and crosses, is magnetized in one of the directions of easy magnetization and about one sixth are magnetized in each such direction as long as no magnetic field is present. When a field is applied in some direction as shown in Fig. 3(b), and gradually increased in strength, the magnetizations of the domains change one at a time so that their directions coincide more nearly with that of the magnetic field. When the field has been increased to such a strength that practically all the domains are oriented as shown in (b), a second process takes place: the magnetization changes slowly in direction until finally it is parallel to the field, and then

changes no more—the material is said to be saturated, as shown in (c).

Fig. 3 is drawn to illustrate the changes in magnetization that occur in a single crystal of iron. The iron which we ordinarily see, however, is composed of a great many minute single crystals, but the changes in magnetization that occur in each one of these crystals are just those which have been described, the magnetization of the whole polycrystalline material being the sum of the magnetization of the parts.

As already implied, the first or *sudden* kind of change of magnetization occurs in rather weak fields; for ordinary soft iron a field somewhat larger than the earth's field is strong enough to produce the situation represented in (b) The second or *slow* process takes place in fields from ten to a thousand times as strong as that of the earth. The typical way in which the magnetization of a material increases with the strength of the magnetic field is shown in Fig. 4. The parts of the curve which correspond to the sudden and slow changes are indicated.

The most definite evidence of the existence of domains and of the sudden or discontinuous nature of the magnetization in low fields is the so-called Barkhausen effect. A piece of magnetic material is wound with wire the ends of which are connected to a vacuum tube amplifier. When the magnetization of the material is changed, as by moving a permanent magnet near it, a rustling sound or a series of clicks may be heard in phones or in a loud speaker connected to the output end of the amplifier. Each such click is due to the sudden change in direction of magnetization in a domain, and from measurements of the sizes of the clicks we get our best estimate of the sizes of the domains. Additional evidence of the existence of domains and the changes that they undergo has been

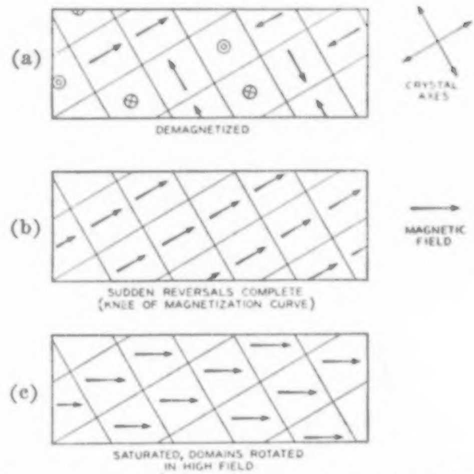


FIG. 3. DOMAINS IN A SINGLE CRYSTAL OF IRON. AS THE MAGNETIC FIELD INCREASES IN STRENGTH THE MAGNETIC MOMENTS OF THE DOMAINS FIRST CHANGE DIRECTION SUDDENLY (*a* TO *b*), THEN ROTATE SMOOTHLY (*b* TO *c*).

obtained recently by spreading colloidal iron oxide over the surface of a magnetic material and looking at it under a microscope. The regular pattern observed is similar in nature to the familiar one obtained when iron filings are sprinkled near a permanent magnet, the fine colloidal particles are necessary in this case

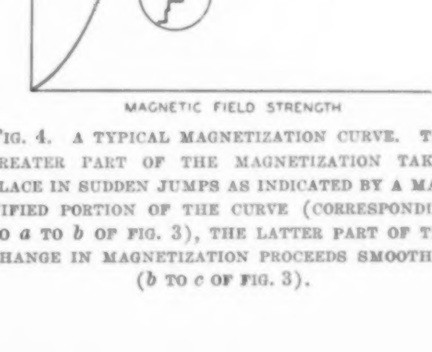


FIG. 4. A TYPICAL MAGNETIZATION CURVE. THE GREATER PART OF THE MAGNETIZATION TAKES PLACE IN SUDDEN JUMPS AS INDICATED BY A MAGNIFIED PORTION OF THE CURVE (CORRESPONDING TO *a* TO *b* OF FIG. 3), THE LATTER PART OF THE CHANGE IN MAGNETIZATION PROCEEDS SMOOTHLY (*b* TO *c* OF FIG. 3).

because the whole scale is small. This micro-pattern changes when the applied field changes, and the difference is attributed to the redistribution or reorientation of groups of domains. Such patterns are obtained only on magnetic materials and are found on them even when the material is unmagnetized.

Magnetic forces between atoms are also responsible for the various magnetic effects caused by straining a magnetic material, and for the converse effect, magnetostriction, which consists in a slight change in the dimensions of a magnetic material accompanying a change in magnetization. In commercial magnetic materials, strain is a very important consideration. To have high magnetic permeability, that is, to be easily magnetizable, a material must be annealed at a high temperature and the fundamental effect of this annealing is the relief of strains which were introduced in the material in its fabrication. Strains of a similar nature but on a much smaller scale are caused by the presence of certain chemical impurities, and the highest permeabilities can be attained only when these impurities have been removed. By such purification the permeability of iron can be increased to over 300,000, thirty times that of the iron ordinarily used in commerce for magnetic purposes. Recently by still more careful treatment, permeabilities of over 1,000,000 have been measured in a single crystal of permalloy, as shown in Fig. 5. Similar permeabilities have been obtained more recently in single crystals of pure iron and of iron containing 4 per cent. silicon.

For some purposes large strains are desirable, the larger the better. To make a good permanent magnet such as those used in loud speakers, great internal

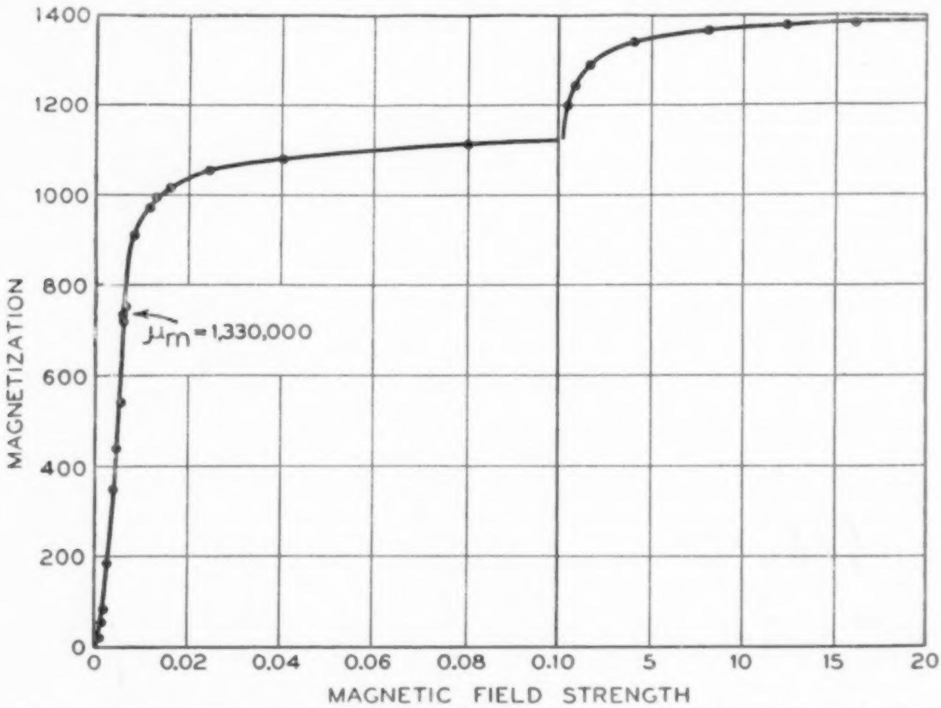


FIG. 5. A MAGNETIZATION CURVE OF A SINGLE CRYSTAL OF PURE IRON SHOWING UNUSUALLY HIGH PERMEABILITY, μ_m. (BY P. P. CIOFFI).

strains varying rapidly from point to point in magnitude and direction are produced by "precipitation hardening," the same mechanism as that which operates to produce the great mechanical strength in steel. Technically this permanency is often measured by the "coercive force," which in modern materials is about ten times that which was attainable a few years ago.

These internal strains are somewhat analogous to the ordinary mechanical strains that would exist in a group of rectangular wooden blocks piled together in a box. Due to the pressure of neighboring blocks, each block is held in a fixed position. This analogy may be used also to illustrate the fact that high internal strains are necessary for good permanent magnets. If each block represents a magnetic domain it can readily be understood that the greater the strain the more the mechanical force necessary to turn or twist one of the blocks in the middle of the pile, and so also the greater the magnetic force or magnetic field necessary to change the magnetization of a domain. Thus, when the strains are large, once a high magnetization is attained it is difficult to change, it is more permanent.

New materials and processes and new theories and explanations have come into existence recently and have mutually aided each other in their development. The new magnetic materials and processes may be expected soon to have a great influence on engineering problems, and the new theories and explanations have made it possible to write a connected story of magnetic theory.

COMMENTS ON CURRENT SCIENCE

By SCIENCE SERVICE[1]
WASHINGTON, D. C.

PRESSURE CONDITIONS OF 95 MILES IN EARTH EQUALLED

Using newly designed equipment man is now producing pressures in the laboratory comparable with those which occur nearly 95 miles within the earth! Professor P. W. Bridgman, of Harvard University, and experimentalist on high pressure, has just announced that his apparatus can now squeeze materials with a force of 700,000 pounds to the square inch.

If one calculates how much rock it would take to create this pressure (allowing a rock mass of 200 pounds per cubic foot) the answer comes out that 504,000 feet of rock are needed. This is a depth of over 95 miles within the earth. By comparison the deepest oil wells that man drills go only a little more than 11,000 feet into the earth. There they fail because the side walls squeeze the drill in a grip of rocky firmness.

The new pressures are over twice as great as any which Professor Bridgman has previously reported. This advance was made possible by a new design of his pressure chamber in which a tremendous pressure is not only present inside (to squeeze the test material) but also subjects the outside to a high pressure to keep it from bursting.

The little pressure cylinder is cone-shaped and is pressed against a steel collar simultaneously as the carboloy plunger presses on the test materials.

One of Professor Bridgman's new discoveries is that extreme pressure turns tellurium—ordinarily like sulfur and non-metallic—into a form which has true metallic properties. Under the severe pressure, too, Professor Bridgman was able to create new forms of bismuth and gallium. Ordinarily these elements behave abnormally, like ice, in that they contract on melting. Most elements expand on melting. By high pressure it was possible to make bismuth and gallium assume forms which also expanded on melting.

ARTIFICIAL RADIOACTIVE MATERIALS IN CANCER THERAPY

Investigators for some years have been smashing atoms in giant apparatus and turning nearly all the elements from one form into another by transmutation. With most of the elements now rendered radioactive at will, tests are under way to determine the biological usefulness of these new tools of science.

The newest instrument in the field of making artificial radioactive materials for biological experiments is the giant cyclotron of the Biochemical Research Foundation of the Franklin Institute. It is to be used to create quantities of materials for cancer therapy. It is quite conceivable that such materials, artificially prepared, may some day displace time-tried radium and radon in cancer treatment.

Among the benefits which would appear are: (1) the synthetic radioactive materials would have short lives and turn, in a few days, back into inert elements without effect on the body, and (2) almost any element seems capable of being rendered radioactive.

The significance of point 1 is that while "seeds" containing radon can now be "planted" within tumors the disintegration products can keep giving out

[1] Watson Davis, director, Frank Thone, Robert D. Potter, Jane Stafford, Emily C. Davis and Marjorie Van de Water, staff writers.

radiation long after the need for it is passed.

The meaning of point 2 is that a good way to treat cancer would be to find some element or chemical combination which would localize in the diseased tissue. If such a combination could be found the chances are that it would be made radioactive with the hope that it would give off radiation directly inside tumor tissue; rays that could destroy the cancerous growth.

This getting "inside" the tumor seems important, for external sources of radiation have an all-too-little specificity for malignant tissue. The rays can kill such tissue, but in so doing they also harm the surrounding healthy tissue.

SELECTIVE MOLTING AS AN ANALYSIS OF LIVING MATTER

N. A. Iljin, of the Soviet's Wool Laboratory, building upon the research of others, found last year that he could by single doses of thallium compounds make sheep shed their wool, leaving them naked as if they had been shorn. This is particularly effective for such sheep as those of the meino variety with uniform fine curling fibers.

Now he has discovered a way to apply the thallium molt to those less improved, more hardy sheep with mixed wool, whose fiber has been of little value because it is largely coarse and not uniform. If the thallium dose was small, only about 9 milligrams, the fine wool predominately fell out, if it was 12 to 13 milligrams both coarse kemp and fine fibers molted. This may possibly have economic importance.

There are difficulties, however, for thallium is a metal poisonous to plant and animal life. Iljin warns of "certain harmful by-effects" and in past years warnings have been issued here in America as to its danger. Numerous deaths followed use of thallium compounds in depilatory preparations. It removed hair with such great efficiency that those who used it became bald. Effective in fighting rodents and insects, even this use is discouraged because of the danger to human beings.

The Soviet investigator, however, has conducted his experiments more for the sake of biology than the wool industry. He calls selective molting in his sheep an example of the analysis of living matter by means of chemical action. Different doses of thallium promise to distinguish between sheep of different genetic strains. Selective molting is considered by Iljin "a proof of the possibility of a physiological distinction between morphologically different structures," a sort of chemical filter for unscrambling the mixtures blended by heredity.

LIFE AT VERY HIGH ALTITUDES

Life at very high altitudes, such as on the upper slopes of Mt. Everest, for example, is strangely different from ordinary living, it appears from the description given by Dr. C. B. Warren before the Royal Geographical Society in London. Dr. Warren was one of the medical officers of the 1936 Mt. Everest expedition.

Difficulty with breathing, of course, is one of the most noticeable changes and apparently is the first difference felt on ascending to higher altitudes. When resting, breathing goes on at about the normal rate, Dr. Warren observed, but the slightest exertion increases the rate, and the increase is way out of proportion to the amount of exertion. A short stroll presumably would leave a man breathing as fast as if he had been running a race. The breathlessness and the sudden awakening at night with a slight feeling of suffocation disappear, however, when climbers get used to the higher altitudes.

Another peculiar feature of life at high altitudes is the feeling of muscular weakness and lassitude.

"For the first few days at Camp III, I found that I was always longing to sit down and do nothing," Dr. Warren reported. "I can only compare the feeling to that sense of weakness which is experienced on first getting up after a long illness."

"A very distinct disinclination for serious mental work" was experienced at altitudes above 20,000 feet. Hearing and vision are less acute at high altitudes, according to some observers, but Dr. Warren did not notice these changes on the Everest expedition. Irritable tempers have also been reported as a feature of life at high altitudes, but Dr. Warren found that in spite of "provoking" conditions, no serious quarrels occurred.

Bracing mountain air is usually thought to stimulate the appetite. At really high altitudes, the opposite is apparently the case. Dr. Warren found that at 20,000 feet members of the party ate far too little, and consequently lost weight, although they thought they were eating enormously.

MAN'S FUTURE DEPENDS ON WHAT HE DECIDES TO EAT

Each of us is called on to make an important decision three times every day: What we shall eat for dinner, for breakfast and for lunch. Man's future depends very largely on what he decides to eat. That prediction comes from Dr. George R. Minot, of Boston, Nobel laureate, who discovered that liver would cure pernicious anemia.

Investigators have learned what should be eaten for good health and growth and even for long life and improvement of the race. Foods that are filling and energy-giving, like meat, potatoes and bread, are not enough. In addition, the diet should include what are called the "protective foods," because they protect us from serious ails such as scurvy and beri-beri and rickets, and from many minor degrees of undernutrition and poor health. Fresh fruits and vegetables and dairy products are protective foods. Statistics of food supply for the past two decades show a shift toward greater consumption of these protective foods. This shift is now being credited with having kept up the public health through the years of the economic depression. It is because of this shift, also, nutritionists believe, that boys and girls are entering college better developed at a slightly earlier age than their fathers and mothers.

Not enough of us, however, are making the three-times-a-day decision as wisely as might be. About half of us are eating a third-rate diet, a survey by Dr. Hazel K. Stiebeling, of the U. S. Bureau of Home Economics, revealed. The reason is not all a matter of pocketbook either. As might be expected, diets were very poor in families where the total food expenditure was $85 per person per year. But at every spending level above $100 per person per year some families succeeded in getting very good diets.

ROLE OF ENVIRONMENT IN MENTAL DISEASE

Fresh evidence of the power of social influences to bring on mental breakdown and disease has recently been given by the tragic story of five men who were playmates as little boys and who all are now patients in the same hospital for mental disease. One of these patients had enough understanding of the situation to bring it to the attention of the psychiatrist, Dr. J. McV. Hunt, of Brown University, who reports the circumstances in the current issue of the *American Journal of Orthopsychiatry*.

The five patients were members of a group of fifteen boys who grew up together in a poor neighborhood of Washington, D. C. Many of the boys had no parental guidance. When about ten years old they began to play around a slaugh-

terhouse and horse barns in the neighborhood and were initiated into sexual perversions by men around these two places. At the same time some of the boys regularly attended a neighborhood church where emotional revivals were frequently conducted. Some of these boys entered violently into the conversion experiences and resolved to give up their sexual perversions. Later, these resolves were broken. Each broken resolve made the boys feel more guilty, so finally they were almost continually miserable.

Some boys escaped this constant conflict. They were more closely watched by their parents and did not join the homosexual ring, or had anti-religious parents and so never went to church or revivals.

All the boys, and only those boys, who experienced the religious conversions and took part in the sex perversions subsequently were committed to institutions for mental disease. The conflict between the two influences was evidently too much for them, and mental breakdown and disease resulted.

Dr. Hunt points out that the community situation is not unique, although it does not in itself prove any theory of the cause of mental disease.

APES CAN LEARN HOW TO WORK IN COOPERATION

Pessimists despair of cooperative harmony among men. War, they declare, is inevitable. Common endeavor is an unnatural, artificial thing at variance with man's true nature.

Psychologists, unemotionally testing the truth of such claims, have stated their finding that nothing in man's nature exists to prevent world peace and cooperation for the common good.

Even apes can be taught to work cooperatively, it has been found in experiments at the Laboratories of Primate Biology, Yale University. The results, as reported by Dr. Meredith P. Crawford, are illuminating in connection with attempts to foster human cooperation. In his experiments, pairs of apes were taught to operate a food vending machine that one alone could not work.

(1) Motivation is all important. Unless the animal wants to work, it is useless to try any cooperative venture. The willing animal in such a case seems to know better than to bother with the unwilling one; he just abandons the project.

(2) Education is important, it was found. Both animals must be trained in the skills necessary for the task. Although sometimes the trained animal will make crude attempts to teach his untrained team-mate, the ape does not seem to make a good instructor. When both know what they must do, one takes the leadership and guides or encourages with gestures and cries, his associate in the task.

(3) Friendliness is important. Apes, like men, have pals of whom they grow very fond; with others they do not "click." For best working conditions, mutual regard is essential.

(4) Attitude of the cooperating animals is important. An individual ape is not always the leader or always subordinate. Some are more successful as the superior.

In one team, Bimba was leader and Bula subordinate. In another pairing, Bula became the leader of Beta. As leader, she increased her gesturing solicitation of help, and cooperation was speeded.

Desire, education, friendliness, leadership—are these the essentials also of human cooperation?

DRAW-CASTING COPPER RODS

One of the older arts of metallurgy is the fabrication of castings by pouring molten metal in a mold and allowing the whole mass to cool. Then the mold is broken away and one has the casting.

The method, of course, is a great advantage over the alternate task of trying to fashion the crude block of cold metal in the desired form.

The art of making castings, then, is old but there is a new technique which is only now coming into production. It is called draw-casting. Most people have never heard of it. It consists of drawing, directly from a bath of molten metal, rods and tubes of copper.

Dr. Byron E. Eldred, new president of the Engineers Club, New York City, and one of the nation's few remaining independent research scientists, is the inventor of draw-casting.

Dr. Eldred melts copper in a furnace which has one or more holes in the bottom. In each of these holes is inserted a copper rod that is going to be the "parent" of hundreds of feet of additional rod the same size. These parent rods are cooled by a surrounding water chamber and transmit their coolness up into the molten copper. Around each of their tips the melted metal starts to "freeze" and in turn becomes cooler. As the metal in the bath freezes, from the inside out as it were, the rods are pulled out and continually solidify more metal within the furnace.

The process, in one sense, reminds one of the old-fashioned method of making candles by dipping. At each dip the cool candle froze more crystals of wax and the candle continually grew larger and fatter. Since Dr. Eldred is not seeking "fat" copper rods he continuously pulls out the newly frozen copper at the end of the rods and gets continuous production that is a time and effort saver over present casting and rolling and drawing methods.

GRAVE OF AN UNKNOWN VIKING

Denmark has discovered its first Viking ship grave. The place where the ship lies, in a cornfield near the sea, has been roofed over and made an exhibit. All that is left of the barbaric, medieval burial has been treated by magic of modern chemicals to prevent it from disintegrating further.

The unknown Viking, thus brought into the spotlight, was perhaps one of the Danes who harried Britain and other European lands, in wild voyages of adventure. He lived about 950 A.D. in the time of that quaintly named king, Harold Bluetooth.

When this unknown Viking died, his ship was dragged up from the sea to a high place. His favorite horses and dogs were brought on board and slain. Attendants came laden with the Viking's weapons and articles he might need on the mysterious voyages of the future world. Then they covered the whole ship tomb under a mound of earth.

But the Viking did not rest in peace, long. His ship was visited by robbers, who carried off everything valuable they could find, and the body of the Viking besides.

When a Danish chemist arranged with the Danish National Museum to excavate the mound near his home, recently, he brought to light this story of medieval burial and robbery.

What remains is this: the foundation of the ship, a long, slim craft, 70 feet by a mere 10. The proud dragon head and the roof over the center long ago had caved in. But the excavators found iron spirals which made part of the dragon's mane, and iron rings belonging to the mast, and several thousand iron rivets of the ship.

Bones of 11 horses and four hunting dogs were found, 45 iron arrow-heads and a few small ornaments that show the splendor of accoutrements in the Viking world.

MAPUNGUBWE

A hill named Mapungubwe, on the

bank of Kipling's "great, greasy, grey-green Limpopo River," has been yielding graves and other clues to South Africa's past.

Awe-struck natives always said climbing Mapungubwe meant death. Their ancestors had buried treasures up there, and no one dared even to point to the sacred hill, in the wild region where it lay. But five years ago, a group of white men located the mill and found what they hoped for—buried treasure. It was, in fact, a skeleton with numerous ornaments of gold plate.

Fortunately, the treasure hunters were educated men, and one reported the find to the University of Pretoria. From then on, Mapungubwe has been probed by eager men, seeking a long-lost chapter of prehistory.

In an archeological volume called "Mapungubwe," Professor Leo Fouche, of the University of Pretoria, and others give a progress report. Excavations have dispelled native mysteries, showing that the hill was occupied by two separate peoples. After several centuries, they left. There was no fighting, no hasty departure, judging by lack of confusion in the ruins.

But before the people went down the hill for the last time, they apparently buried their sacred objects with their chief. One grave, nicknamed the Scepter Burial, contained a skeleton buried with a gold scepter in one hand. This episode in African prehistory happened in the Middle Ages, so the evidence mainly suggests.

Archeologists are now puzzled to know what these early Africans were like. Skulls they have seen are not true Negro type. They may represent a mixture, even including distant foreigners.

Urging extended digging to north and south of Mapungubwe, Professor Fouche declares that deeper knowledge of native failures and achievements in Africa's past may aid Britain in improving its relations with native subjects.

GERMAN SOYBEAN SUPPLIES

Germany, seeking economic self-sufficiency in raw materials and foodstuffs, especially in the all-important oils and fats, has undertaken the encouragement of large-scale cultivation of soybeans, hitherto imported in considerable quantities from Manchuria.

Systematic testing of the hundreds of known varieties of soybean is in progress, as well as breeding to produce new kinds better adapted to the German range of soils and climates. Werner von Haken, an agricultural economist, has blocked out areas where good results may normally be expected, and others where the chances are not so good.

Roughly a fifth of the total area of Germany is in the first-choice soybean regions. These are principally in the southwestern and central parts of the country. An additional two fifths is second-choice soybean territory, where success will be largely conditioned by local conditions and the skill of the individual farmer. The rest of the land, in the north and east and the mountainous south, is not recommended for soybean culture.

Herr von Haken's discussion contemplates large use of soybeans as human food. The Chinese have for centuries made a large variety of palatable dishes out of soybeans, which constitute the principal source of protein food for most of the population. Herr von Haken believes that crowded, blockade-threatened Germany would do well to follow the Chinese example.

Despite the fact that Manchurian soybeans can be imported into Germany more cheaply than they can be raised there, Herr von Haken feels that large-scale cultivation at home is desirable, even aside from questions of national policy. The imported soybeans, he points out, are a mixture of varieties and therefore do not cook uniformly. He also states that the home-produced soybeans are usually superior in flavor.

MARIE CURIE—HER LIFE WORK[1]

By Dr. FRANCIS CARTER WOOD

INSTITUTE OF CANCER RESEARCH, COLUMBIA UNIVERSITY

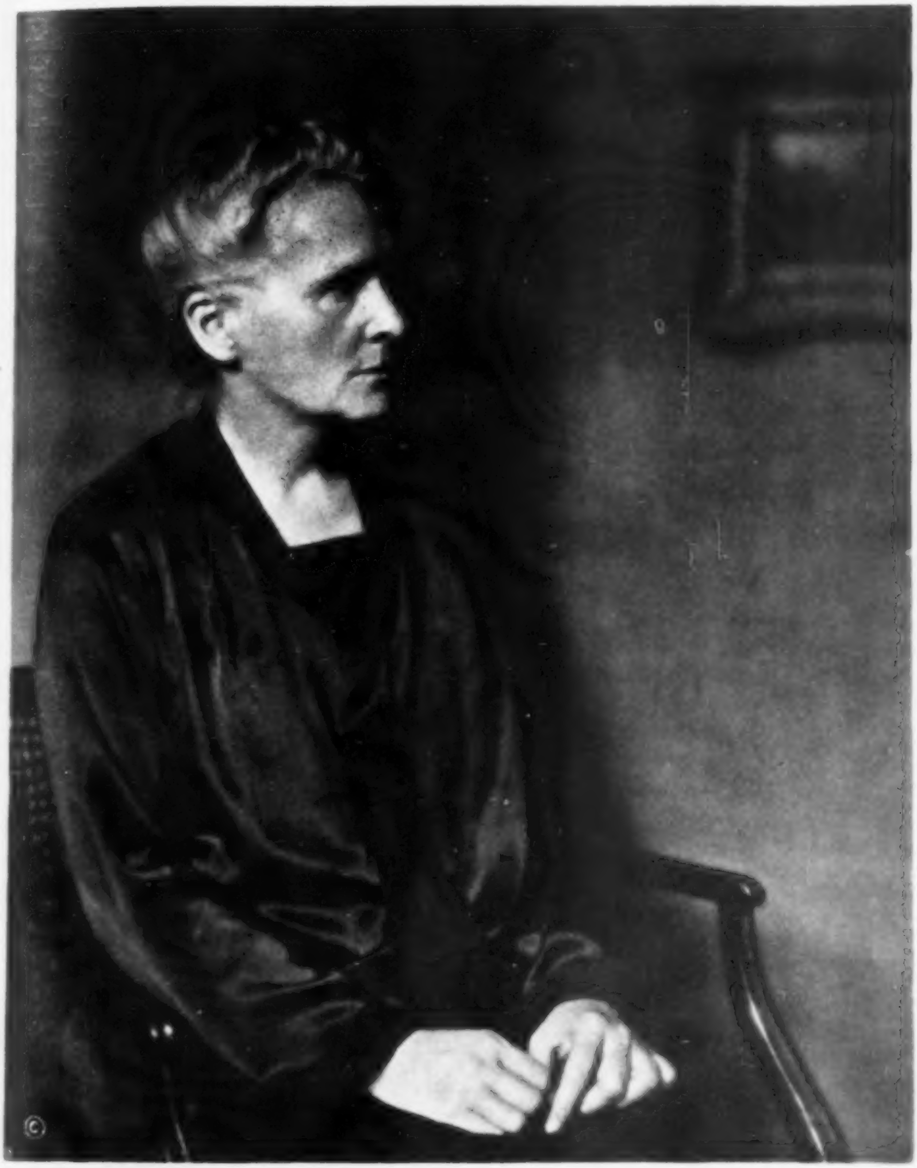
A STROLLER in the Latin Quarter of Paris in the winter of 1897 who happened to look into a small building used for storage on the rue Lhomond—that part of old Paris where the French preserve by the street names the glory of their scientists—would have seen a tall handsome man with a brown beard and a woman with a beautiful intellectual face gazing intently at some glass receptacles which were aglow in the darkness with a curious greenish light; even a thin vapor arising from some of the fluid in the basins was faintly luminescent. This couple was Pierre and Marie Curie, who after a day of hard labor in their workshop had returned after dinner, as they frequently did, to see that things were all right for the night and to wonder at this curious auroral glow that was produced by the hitherto unknown element, radium, which they were in the process of isolating from the ores of uranium. This faint luminescence was due to the alpha rays which the radium and its emanation gave off, bombarding the atoms of the air, changing their chemical nature and exciting their electrons, and the Curies were observing the birth of the world of the infinitely little and the dawn of the new alchemy. Though they did not know it, their discoveries were to revolutionize the opinions of 2,000 years, completely transform modern physics, aid astronomers in their study of the stars, restore to life and health thousands of human beings, and inspire a host of investigators along innumerable lines of study in wholly new fields. It is of interest to discuss briefly what led to this remarkable discovery, for in science no one stands alone for if Roentgen had not discovered in 1895 the rays which bear his name, the name of the thirty-year-old Marie Curie might never have been known to fame.

About the year 1890 physics was supposed to be more or less finished, for it was felt that all the important laws had been discovered, and the only thing remaining was to measure the known phenomena more accurately. It is true that certain scientists in England and Germany were studying the luminous bands and other phenomena which occur when a fairly high-voltage electrical current is passed through a glass tube containing various gases at low concentration. Faraday and Crookes were two who had spent time on this subject without casting much light on its nature. About 1890 an English physicist, J. J. Thomson, studying the effects of the transmission of electricity through rarefied gases, began to make observations which pointed to the fact that the explanation of the luminous phenomenon must be that under the influence of electricity the gas in these laboratory aurora is broken down into electrified particles, for the colored streamers were deflected by a magnet or an electric current outside the gas-containing tube, as Plücker had described in 1858.

It was while working with such a tube in 1895 that Roentgen noticed that photographic plates lying on a table nearby were fogged, and in a few months the discovery of x-rays was made. He, as Plücker in 1858 had noted, saw that the glass of the tube assumed a bright greenish color while the current was passing, and it was thought at first that this greenish color was the source of the radiations.

Poincaré, the famous French mathe-

[1] Read at a memorial meeting held at Columbia University on January 20, 1938.



To Dr Francis Carter Wood
with my best wishes
M. Curie.
November 8, 1929

matician, showed the first x-ray pictures taken by Roentgen, at a meeting of the Paris Academy of Sciences in January, 1896, and in the discussion which followed made this same suggestion as a possible explanation in reply to a question by Henri Becquerel. The father of Becquerel had been a famous chemist, and the son possessed a considerable supply of uranium salts which had come into his possession after his father's death.

Uranium salts give off a greenish phosphorescence when exposed to light, so Becquerel covered some photographic plates with black paper, laid the uranium salts on them together with some metal objects and, to his astonishment, found that he had a Roentgen shadow picture. Being a scientist, he tried some uranium which had not been exposed to light and found that it photographed just as well. Then he took some fresh samples of very pure, recently prepared uranium and found that it did not photograph. Becquerel recognized that the photographic effect must lie either in the atoms of the uranium or in a contaminating substance present. To-day we know that the uranium breaks down in the course of years into radioactive substances. For a long time these rays were called Becquerel rays. Becquerel was unable to continue these investigations and suggested, late in 1897, to Pierre and Marie Curie, who shortly before had been married, that they follow up this discovery and find out what was the substance in uranium which possessed photographic capacities.

This selection had a touch of genius in it, for Pierre and Marie Curie combined that persistent and clear-sighted intellectual energy which is so necessary for scientific discovery. They were poor, struggling to do work under disadvantageous conditions, and gladly turned to this new field where Pierre Curie's knowledge of physics and Marie Curie's knowledge of chemistry were needed to solve the problem. In 1898 they announced the discovery of radium.

There has been much discussion as to the part which each played in this discovery. Marie Curie has always said that it was a combination of two closely related minds. It was her duty to do the arduous chemical analyses which were necessary to find the minute traces of radium in the ores with which they worked. They tested all the minerals in the college collection and found a few which had photographic power and also were capable of ionizing the air about them so that it would carry a minute electric current instead of acting as a very perfect insulator, as does ordinary air. These ores were chiefly those containing uranium. It was Pierre Curie's share, as a trained physicist, to take each substance—and there were over thirty known elements in the uranium ores—and determine, with an apparatus which he had invented some time before, the amount of ionization that each sample produced. Thus, as they eliminated metal after metal, they finally found that mixed with bismuth and barium were minute traces of intensely ionizing substances. The first was polonium, the second radium.

The quantity of current which flows when the ionization is produced is a measure of the radioactivity of the element. Radium salts are never sold by weight, but by the ionization which they produce as compared to a standard, and the x-ray used in the treatment of cancer is also measured by this means. In this phase of their work they fell back upon the discoveries which had been made in the past showing that not only x-rays made air a conducting medium, but that all gases became conducting when a current of electricity was passed through a glass tube containing a rarefied gas, thus returning to the early work of Faraday and others who had noted this phenomenon.

Now we know that the currents through

these tubes or through what is called an ionization chamber are produced by the separation from a gas of the electrons, a swarm of negatively charged particles so minute that we shall never be able to see them, which themselves being charged with electricity or, according to the modern view, consisting of an electrical charge, are able to transfer a current by moving from one pole to another. Faraday many years before had brought forward a similar idea to explain the conduction of electricity through fluids and the basis of all electrical deposition of metals which had long before reached a practical development as every piece of Sheffield plate testifies, for the silver in a solution of silver salt is carried from one pole and deposited upon the copper, which forms another pole. To-day we know that x-rays are produced by the beating of these electrons upon the surface of a metal, which so perturbs the atoms of that metal that they radiate x-rays, just as an electric current in the ordinary lamp bulb heats the filament and makes it give off electrons, as Thomas Edison showed in 1883 without knowing the explanation.

Thus Marie Curie by her chemical discovery of the element radium inaugurated what may be called modern physics, and it must have been to her a marvelous satisfaction that her daughter, Irène Joliot-Curie, has followed in her footsteps, making one discovery after another, which would render the name Curie imperishable had her mother never been famous. But it has been granted to no other woman so to revolutionize by a single discovery the whole subject of atomic physics.

When Pierre Curie in 1903 found that radium gave off heat, many of the theories of physics, especially that dealing with the conservation of energy, seemed to be shattered, but shortly afterward it was shown that this heat was produced by the breaking down of the atoms of radium, and the heat production could be accounted for by the slow, spontaneous destruction of this newly discovered element which in some 1,700 years loses half of its substance. The final stage which this breakdown reaches is lead, a lead which can not be distinguished from the ordinary plumber's lead, except by the most refined methods of analysis.

In passing, it may be said that this fact has been used to measure the age of the earth, for the minerals which contain uranium also contain lead and the amount of this lead gives a measure of the number of years that the uranium has been in existence. Hence, like the rings of the great redwood trees in California which show that they are the oldest living creatures, so the amount of radium lead in minerals points to millions of years of life of an ore in which the original uranium has been slowly changed through a series of breakdowns into lead.

The first radium obtained was very impure, and after 1898 Pierre Curie interested himself in the physical properties of this new substance and discovered that it gave off particles which could pass through air for a distance of one to two inches and then suddenly stop. These are now known as the alpha particles from radium and are actually electrified atoms of helium gas. The gamma and beta rays, the latter being negatively charged particles, were found by others, chiefly Rutherford.

Marie Curie then devoted herself to the separation of large quantities of radium from the residue of many tons of uranium ore from Joachimstal in Bohemia, which were placed at her disposal by the Austrian government. After years of hard work requiring a most laborious series of chemical separations and crystallizations of the impure product, she finally succeeded in making a small quantity of absolutely pure radium, the chemical properties of which she studied. She also prepared sealed tubes containing

carefully measured amounts of the pure salts which are deposited in the various bureaus throughout the world, including the Bureau of Standards in Washington, to serve as standards for the measurement of radium, just as the standard meter and standard yard are deposited and used for the checking of accurate measuring instruments.

In the meantime, a host of investigators, including the famous Lord Rutherford, who died only a few months ago, began to investigate this profitable field. The Curies had noticed in 1899 that all the apparatus and even the walls of the room in which they worked became radioactive. It was soon found that radium gave off a gas which is now known as emanation or as radon. This gas is really the active substance which characterizes radium, for, if the gas is pumped off, radium ceases to radiate, but in the course of a few days regenerates more radon, which can again be pumped off and used for practical purposes, for a great deal of the treatment of cancer is done with radon rather than with radium. This radon gas has a very short life, losing half of its value in a little over three days.

Further studies showed in the course of the breakdown of radium that a large number of products were obtained, some with an extremely short life measured in thousandths of a second, others which lasted for millions of years. In the uranium-radium family there are sixteen known members, the last being lead. It was soon found that thorium also possessed radioactivity, and the thorium family has thirteen known members, ending again with lead. Later an actinium family was found, also of many members, and its termination is also in lead. But this was the work of other hands.

Others also invented elaborate theories for the constitution of matter based upon Marie Curie's discoveries. We believe for the moment that an atom of matter is composed of a central nucleus, which contains neutrons and fragments of hydrogen known as protons, and around this as a center rotate the electrons, one for hydrogen and up to 92 for uranium, the metal with the highest atomic weight. The Curies vaguely dreamed of this celestial system with a central sun and surrounding planets, and Irène Curie just missed the discovery of the neutron by a few months. The central mass of neutrons and protons determines the nature of the element and the electrons control its chemical reactions. The electrons can be pulled off by exposure to Roentgen or gamma rays and heat. This does not change the actual chemical nature of the substance, for the atom which has been stripped of some of its electrons collects these quickly from neighboring atoms and becomes normal again. In a gas this recovery takes only a few minutes. But Lord Rutherford showed in 1919, that if alpha particles from radium are allowed to play upon nitrogen gas some of the nitrogen is destroyed and changed into oxygen and hydrogen. Apparently the helium particle is able to break into the center of the atom and change the atomic weight, for nitrogen has an atomic weight of 14 and the oxygen produced of 17. Helium with an atomic weight of 4 and nitrogen with 14 makes an atomic weight of 18 against the oxygen with 17, leaving a missing weight supplied by hydrogen with an atomic number of 1. Both helium and hydrogen can be found in the sealed tube originally containing only nitrogen. This was the first artificial production of new elements and is the field in which Irène Curie has made herself famous.

Whether the radium which Marie Curie discovered will ever be produced artificially by some such process is as yet unknown. Probably it will be found that the amount of energy used up is so enormous that the transformation must remain a laboratory experiment, but Pro-

fessor Ernest O. Lawrence, of California, has produced several pounds of radioactive sodium by bombarding ordinary salt with atomic bullets, which has certain interesting uses in that if a small quantity is placed on a person's tongue and an electrical machine attached to his foot, it will be found that this sodium is in a few moments in the general circulation, thus testing the speed of absorption. Radioactive iron is being used to study the way in which anemia is cured by iron, and a host of interesting problems have developed from this work. All these things are mentioned merely to show the marvelously fertilizing effect of a single important discovery.

In the light of all these astonishing events it seems as if the pioneer work of Marie Curie was very simple, but this is because the facts have become a part of everyday knowledge and it is the gift of the genius such as this woman possessed to interpret the results of simple chemical analyses and to infuse into dull decimals a life of the spirit. Thousands of chemists could have done the analytical work which she did as she employed merely text-book methods, but in her mind lay the power to conceive theories to explain not only what had already been discovered but to open paths for further investigation. In many instances she was unable to carry these on in person, but they were immediately seized upon by others who used the ideas which she had developed to make important discoveries.

Her mind was an extraordinary one. She had no interest in people in general or for the ordinary matters that fill the minds of so large a proportion of the world. She cared nothing for names and titles, as some amusing incidents related in a recently published biography by her daughter, Eve Curie, show. She cared only for a few friends and her scientific work. In this field she had the power of enormous and prolonged concentration on a problem. In her later years, despite serious ill health, she worked in a variety of fields and contributed to all of them. She studied the causes underlying the destruction of cells by radium, for example. During the world war, when her laboratory was closed, she applied herself to the practical use of x-rays and did valuable work in organizing and directing a field system of portable x-ray machines by which surgeons could be guided in the treatment of injured soldiers. It must have greatly pained her, who longed to benefit the human race by her labors and refused to patent or accept money for her method of refining radium, to know that the discovery of radium, which has meant so much for the saving of human life, was also used extensively to coat luminous tapes to guide soldiers through the barbed wire entanglements of the battlefields and to illuminate gunsights in order that men might shoot each other with greater facility.

Her direct contributions to the treatment of cancer were few. She was immensely interested in the work of the Curie Institute under Dr. Claude Regaud, for which she was responsible, and was of great help in teaching the staff the technique of preparing and measuring the radium they were using.

It was interesting to see her mind at work. As she passed through the great Physical Laboratories of Columbia University on her first voyage to America she must have thought of the abandoned storehouse in which she had worked. While nothing interested her but some of the subjects with which she was familiar, she would immediately stop and discuss any work in her own field with a member of the staff, wholly forgetful of time, appointments and the friends who wondered why she did not turn up for lunch, concentrated and interested in the new things that she was able to see in other people's investigative labors. There was not one atom of jealousy in her nature.

That she was a genius there can be no

doubt. True, all genius is aided by circumstances and she might have remained a teacher of chemistry in a French school if it had not been that Becquerel made and tested an erroneous theory, and as a result an opportunity was given to her to investigate a new field of science. But it is true also that many others were working in the same direction, but had failed to accomplish anything.

The argument has been made that because simultaneous discoveries are not infrequent in science genius is merely a question of mass action and if only a sufficient number of persons work on a problem, the discovery will be achieved. But since the pioneer work of Plücker in 1858 innumerable persons had run an electric current through an evacuated glass tube and studied the phenomenon which ensued, though it was not until 1895 that Roentgen found that every such tube gave off x-rays. It is related that one English scientist of great ability noted that his photographic plates were fogged in the neighborhood of such a tube, but instead of searching for the reason, he complained to the maker of the plates that they were defective and obtained a new box. Roentgen had the flash, the intuition, if you will, which made him find out why his photographic plates were fogged. So Marie Curie had the intuition which led her to devise the hypothesis that it was the breaking-down of the atoms of uranium which caused it to give off radiation. Without this working hypothesis radium might not have been discovered for another hundred years.

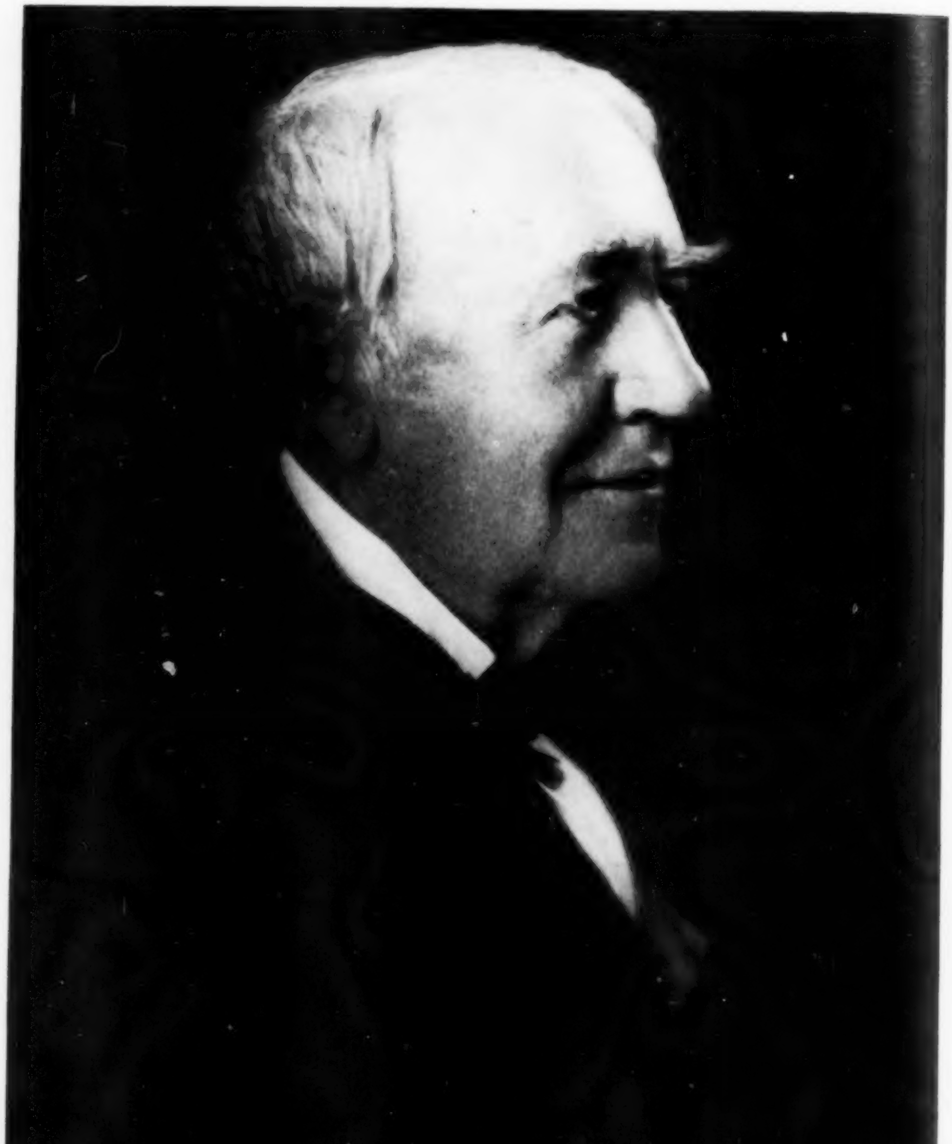
After her husband's death in 1906 Marie Curie was appointed to his chair of radio-physics in the Sorbonne and continued his lectures. In 1910 she published an important work, a "Treatise on Radioactivity" which summarized their labors and those of others up to that time. Later she wrote a charming memoir of her husband, which is too little known, though an admirable translation has been printed in this country. She also published a book on "Radiology and the War" which was drawn from her experiences in organizing a field radiological service for the French army. She continued her scientific researches despite continued ill health and published many short papers on various topics. Her laboratory became a center for research students from all parts of the world.

Much has been made, and I think too much, of the difficult circumstances under which the Curies worked, their poverty and the lack of appreciation in France in the early period of their discoveries, but truly they lived an ideal life. They believed, in spite of her dreams for the emancipation of her native Poland and their desire to help humanity, that they were powerless to change the social order: that if they had had the power they would not have known what to do, and so in working without understanding they would never be sure that they were not doing more harm than good by retarding some inevitable natural evolution. In science, on the contrary, they felt they could accomplish more with their lives than in any other direction; that the field here was more solid and obvious, and however small a territory it might be it was truly their own possession. Marie Curie writes of her early days in Paris: "This life, painful from certain points of view, had for all that a real charm for me. It gave me a precious sense of liberty and independence. If sometimes I felt lonesome, lost in the great city of Paris, my usual state of mind was one of calm and great moral satisfaction. All that I saw and learned delighted me. It was like a new world opening to me, the world of science which I was at last permitted to know in all liberty." Of the abandoned shed which was the best laboratory the School of Physics could give them she writes: "Despite the exhausting work it

was in this miserable old shed that we passed the best and happiest years of our life, devoting our entire days to our work. I shall never be able to express the joy of the untroubled quietness of the atmosphere of research and the excitement of actual progress with the confident hope of still better results. The feeling of discouragement that I sometimes felt after some unsuccessful toil did not last long and gave way to renewed activity. We had happy moments devoted to a quiet discussion of our work while walking around our shed.''

Another and far different person has described the same sensation. ''I do not know how far it is possible to convey to anyone who has not experienced it the peculiar interest, the peculiar satisfaction, that lies in a sustained research. It is a different thing from any other sort of human effort. You are free from the exasperating conflict with your fellow creatures that, for me, is its peculiar merit. Scientific truth is the remotest of mistresses. She hides in strange places; she is attained by tortuous and laborious routes. She is always there, winning you to her, and she will not fail you. She is yours and mankind's forever. She is reality. You cannot change her by advertisement or clamor nor stifle her in vulgarities. Things grow under your hands when you serve her, things that are permanent as nothing else is permanent in the whole life of man. That, I think, is the peculiar satisfaction of science and its enduring reward.''

So I think that if Marie Curie had been asked in her last days, as she looked across to the sunlit mountains of Savoy from her room at the sanatorium at Sancellemoz, what her life had been, she would have replied that it had been full of human affection and companionship with one whom she loved, full of the joys of research, of hard work and of final achievement, crowned at last with the highest of human rewards, the admiration by the few great minds capable of understanding the superb nature of those discoveries which were hers and render her name imperishable as long as the human race exists.



THOMAS ALVA EDISON
FEBRUARY 11, 1847—OCTOBER 18, 1931.

THE PROGRESS OF SCIENCE

THE EDISON MEMORIAL TOWER

The Edison Memorial Tower, a one hundred and seventeen foot concrete monolith on the top of which is a fourteen-foot beacon, was dedicated on February 11, the ninety-first anniversary of the inventor's birth, at Menlo Park, N. J., where Thomas Alva Edison invented the first incandescent electric light.

The tower looms as the highest discernible object for many miles. Surmounting the 117-foot, 8-inch concrete-slab structure is a 13-foot, 8-inch replica of the original incandescent lamp which, illuminated nightly, can be seen for a distance of several miles, serving as an airplane beacon. The foundation of the tower consists of a reinforced concrete pad two foot six inches thick under the entire structure. The space between this pad and the floor of the entrance room to the tower, containing the "Eternal Light," was back-filled with earth for the purpose of adding weight to increase its stability against wind pressure, in the same manner as the keel on a sailboat is provided to counteract the pressure of wind on its sails. The tower is designed for pressure of wind at a velocity of 120 miles per hour. In its construction, which consumed slightly less than eight months, there were used approximately 1,200 barrels of Edison Portland cement and 50 tons of reinforced steel.

The large bulb on the top of the tower was cast by the Corning Glass Works, which fifty-nine years ago, in 1879, furnished from a sketch the first commercial electric light bulb. The replica bulb contains 153 separate pieces of amber tinted Pyrex glass, two inches thick, set upon a steel frame. The bulb is five feet in diameter at the neck and nine foot two inches in diameter at the greatest width and weighs, without the steel frame on which it is placed, in excess of three tons. Inside this Pyrex glass bulb are four 1,000 watt bulbs, four 200 watt bulbs and four 100 watt bulbs. A duplicate of each is so arranged as automatically to cut in should its companion bulb fail. The glass in the Pyrex bulb was placed on its steel frame at the Corning Glass Works, Corning, New York, and then, after being numbered, each piece was dismantled, packed and shipped to Menlo Park, where the work of permanent assembly atop the tower itself was undertaken early in December, 1937.

On seven of the eight sides of the octagonal base are bronze tablets inscribed with descriptions of major Menlo Park inventions. In front of a bronze and glass door in the eighth side, in the concrete base of the tower, is buried a copper box containing, along with several documents, copper plates on which are inscribed the names of the officers and members, past and present, of the Edison Pioneers and the names of the officers and directors of The Thomas Alva Edison Foundation, Incorporated, together with the names of the technical bodies which they represent. The use of copper, apart from its ability to withstand the elements over the years, is in recognition of Edison's inestimable contributions to that industry's growth through the enormous demands for copper metal made necessary by the expansion of the electric light and power industry, in the creation of which Edison was so prominent a factor.

Emblematic of the invention on this spot in 1877 of the phonograph, is a sound system designed and manufactured by the RCA-Victor Company of Camden, N. J. Electrically transcribed phonograph records can be broadcast from the top of the tower ninety-six feet above the ground. There, beneath the huge lamp, are decorated grilles, behind which are wide-range, high-powered, loud speakers.

—*Wide World*

THE EDISON MEMORIAL TOWER

THE DEDICATION AT MENLO PARK, N. J. A GENERAL VIEW SHOWING THE GROUND AROUND THE MEMORIAL, PHOTOGRAPHED DURING SERVICES ON FEBRUARY 11.

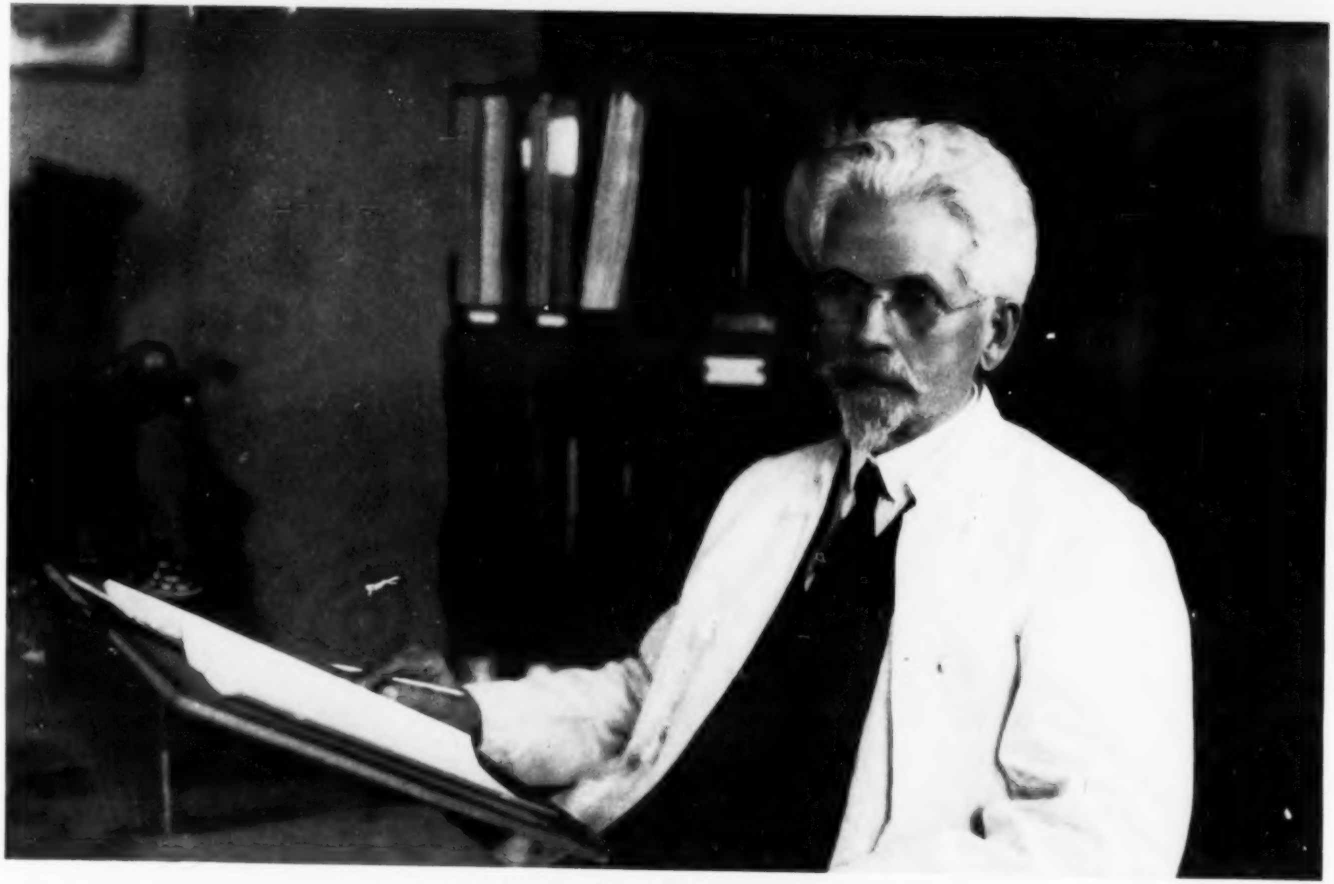
The speakers are designed to transmit chimes, music of all kinds, as well as speech, over a radius of two miles. The group of specially designed, heavy duty amplifiers, with all controls, is located in the operating room in the tower. Here are also installed the transcription turntable and the lateral and vertical sound heads for reproduction of standard or special recordings of all types. This transcription turntable is the highest quality available and, in combination with "hill and dale" (vertical) recordings, which Edison invented and always used, provides extremely faithful reproduction of any type of music or speech. Part of the general installation is a group of eight loud speakers located thirteen feet from the base of the tower; these are designed particularly for speech reproduction over a radius of at least one hundred and fifty feet. They are equipped with a high duty, portable microphone for use at locations provided with connections to amplifiers. Provision has been made for any addition of electric organ or electric carillon, as well as for Westminster chimes, in combination with a time clock, for striking the hour, half hour and quarter hour.

THE MICHIGAN STATE LABORATORY

Recently, at Lansing, one of the country's finest publicly owned laboratories was formally opened by the State of Michigan. At that time, workmen of the Works Progress Administration had almost completed construction of its last unit. Known as the Michigan State Diagnostic, Research and Control Laboratory, it provides facilities for the state's research and laboratory work and has attracted wide attention to findings resulting from extensive experiments carried on by its staff.

The laboratory was opened in 1923

THE MICHIGAN STATE DIAGNOSTIC RESEARCH CONTROL LABORATORY
THE BUILDING, WHICH WAS RECENTLY COMPLETED BY THE STATE OF MICHIGAN IN COOPERATION WITH THE WORKS PROGRESS ADMINISTRATION, HOUSES THE ADMINISTRATIVE OFFICES, THE QUARTERS FOR THE CHEMICAL LABORATORIES OF THE MICHIGAN STATE DEPARTMENT OF AGRICULTURE AND THE PHOTOGRAPHIC DIVISION OF THE MICHIGAN STATE HIGHWAY DEPARTMENT.



HENRY HERBERT DONALDSON

WHO HAS DIED AT THE AGE OF EIGHTY YEARS, HAS LONG BEEN A LEADER IN ANATOMICAL SCIENCE, HAVING BEEN FOR MANY YEARS PROFESSOR OF NEUROLOGY AT THE UNIVERSITY OF CHICAGO AND LATER A MEMBER OF THE WISTAR INSTITUTE OF ANATOMY AND PROFESSOR OF NEUROLOGY AT THE UNIVERSITY OF PENNSYLVANIA. HE IS BEST KNOWN FOR HIS WORK ON THE NERVOUS SYSTEM, WITH SPECIAL REFERENCE TO GROWTH AND THE CHANGES DUE TO AGE.

GEORGE ELLERY HALE

IN WHOSE DEATH THE WORLD LOSES ONE OF ITS LEADING ASTRONOMERS. HE HAS BEEN CALLED "THE GREATEST BUILDER OF AMERICAN ASTRONOMY," HAVING BEEN RESPONSIBLE FOR THE ESTABLISHMENT OF THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO, THE MOUNT WILSON OBSERVATORY OF THE CARNEGIE INSTITUTION OF WASHINGTON; AND THE NEW OBSERVATORY ON PALOMAR MOUNTAIN OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY. HE IS DISTINGUISHED FOR HIS OWN RESEARCH, ESPECIALLY ON THE MAGNETIC FIELD OF THE SUN, AND HAS BEEN A LEADER IN MANY MOVEMENTS FOR THE ADVANCEMENT OF SCIENCE AND CIVILIZATION.

with a one-story brick building containing about 2,000 square feet of floor space, with small adjacent buildings for animals used for experiment, and has been expanded until it now is a half-million dollar plant, complete in every respect.

The new administration building, containing about 33,000 square feet of floor space on its three floors, provides facilities for the State Health Department on its first and second floors, an office for the director and two rooms for the photographic division of the State Highway Department. The third floor is devoted to the chemical laboratory of the State Department of Agriculture, operated under the direction of W. C. Geagley, state chemist. Three animal houses, tripled in capacity since 1934, are constructed so that either may be isolated in the event of an epidemic. Also separate are stables for the 40 horses used in the production of immunizing serums, the manufacture of which is an important feature of the work of the laboratories.

The animal houses accommodate annually about 5,000 guinea-pigs, between 500 and 1,000 rabbits, 50 to 100 monkeys, 3,000 to 5,000 white mice and 30 calves. Most of these are bred locally for use in the laboratory work, though the strain is supplemented each year by pure blood stock, rabbits being imported from Hampstead, England. In connection with the stables is a model horse hospital, complete with a huge operating table to which the animal is tied in a standing position, then tilted back so that he lies in front of the veterinarian in the desired position.

MODERN LABORATORY FACILITIES

AN INTERIOR VIEW OF ONE OF THE LABORATORIES IN THE MAIN BUILDING OF THE MICHIGAN STATE DIAGNOSTIC RESEARCH CONTROL LABORATORY. PERCY O'MEARA, OF THE CHEMISTRY SECTION OF THE MICHIGAN DEPARTMENT OF AGRICULTURE, IS SHOWN EXAMINING THE OPERATION OF A CRUDE FIBER APPARATUS USED FOR STOCK FEED ANALYSIS.

THE NORTH POLE DRIFTING STATION

SAFE removal of the four Soviet scientists from the ice east of Greenland on February 19 brought to a close one of the most unique voyages in history. Deposited by airplanes on an ice-floe 12½ miles from the North Pole on May 21, 1937, the scientists were picked up from a remnant of the same ice-floe 274 days later, 1,324 miles from the North Pole. Though deeply stirring as a spectacular and dramatic adventure, the real importance of this undertaking lies in its scientific revelations and its significant role in the Soviet Union's efforts to study and develop its portion of the Arctic in a thoroughly scientific, practical and systematic way.

In 1936 there were over 50 scientific stations on the islands and mainland of the Soviet Arctic, a network forming a vast semicircle around the central part of the Arctic Sea. None of these stations, however, was within 600 miles of the North Pole. It was to fill this vacancy, to conduct scientific studies in the central Arctic, to report the weather conditions near the Pole, and to provide a base for trans-Polar flights that the station, known as Station 56, was established on the ice near the Pole.

Final preparations for the expedition were begun in the fall of 1936, when a station and air base were established on Rudolf Island at the northern end of Franz Josef Land, 560 miles from the Pole. During the early spring of 1937 planes, specially equipped, flew to Rudolf Island. On May 5, under the command of Professor Schmidt, chief of all the Soviet Union's Arctic operations, a reconnaissance flight was made over the Pole and it was ascertained that heavily loaded planes could land in that area. On May 21, one plane with Professor Schmidt in command landed 12½ miles from the Pole and established the station on an ice-floe which was over a square mile in area and had an average thickness of about nine feet. Three other planes arrived at the station between May 26 and June 6 with all the necessary supplies for a full year's work. For a few

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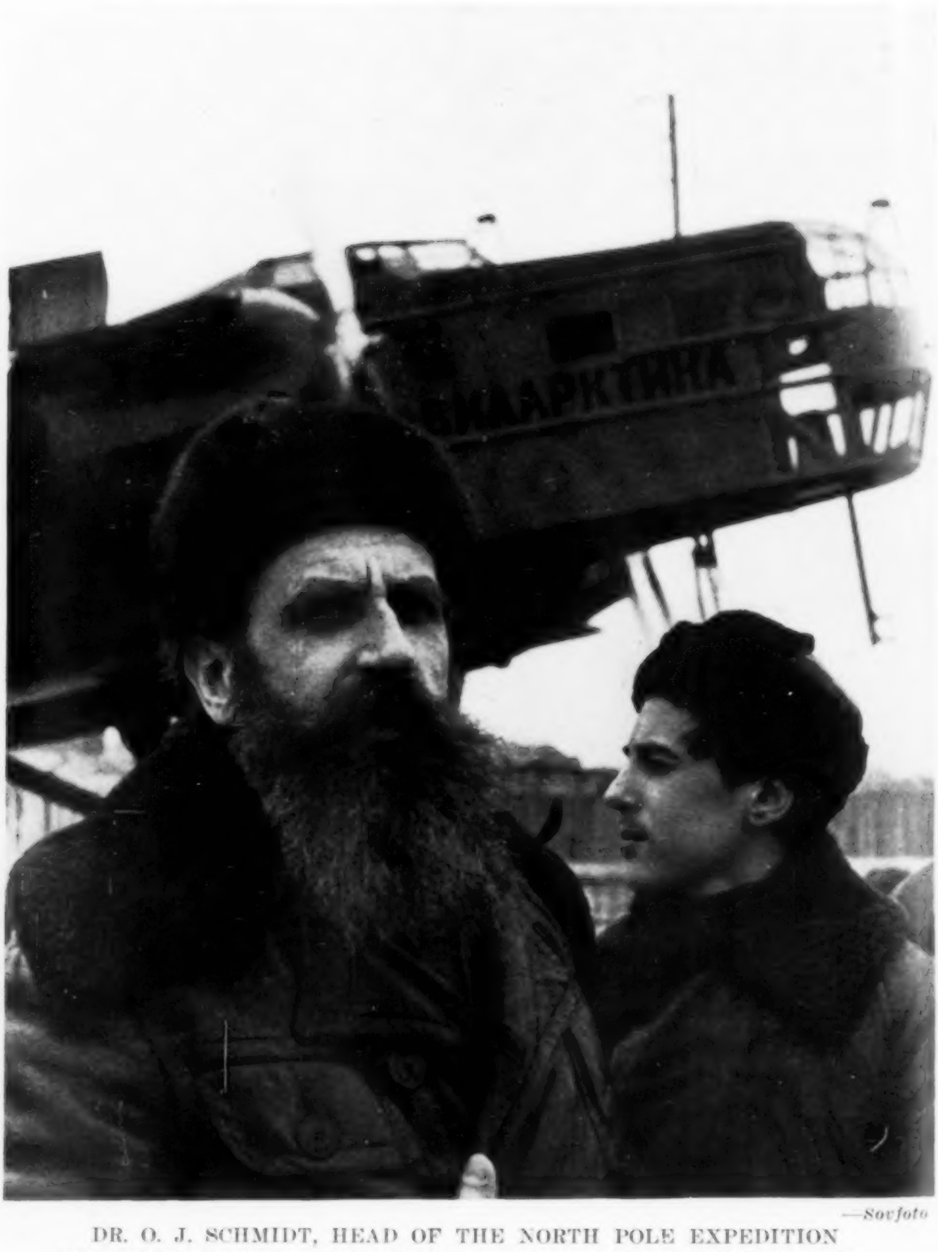
A CATERPILLAR TRACTOR ON RUDOLF ISLAND

HAULING ONE OF THE PLANES OF THE EXPEDITION TO THE STARTING POINT BEFORE TAKING OFF TO THE NORTH POLE.



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DR. O. J. SCHMIDT, HEAD OF THE NORTH POLE EXPEDITION
WITH HIS SON AT THE MOSCOW AIRDROME BEFORE THE TAKE-OFF OF THE EXPEDITION.

hours on June 6 there were 35 men at the station. Then the four planes returned, leaving the scientific work in charge of four men. Besides the leader, Ivan Papanin, the staff consisted of the astronomer, Eugene Federov, the marine biologist and hydrologist, Peter Shirshov, the radio operator, Ernst Drenkel, and Jolly, the dog.

The scientific work of the station began on May 21 and communication was set up with the network of Soviet Arctic stations and other parts of the world. Weather reports were sent out on a schedule of four times per day, except during the trans-polar flights, when reports were made every three hours. The meteorological data thus provided has been of the utmost value to students of world weather conditions and to weather forecasting in Europe, Siberia, Canada, Alaska and the United States. It has revealed that weather in the polar regions is subject to more change than was previously believed and that storms from the North Atlantic penetrate to the Pole itself.

Throughout the drift, the station made careful studies of ice conditions, the waters and currents at various depths, and submarine topography, the sea floor, marine life, the force of gravity, terrestrial magnetism, radio transmission and various phenomena of special interest to students of the Arctic. Thus, an enormous amount of information has been assembled about one of the most inaccessible and least known regions of the earth, which had never before been visited. The conditions for work were extremely difficult and were made more so by rain and excessive melting in the summer, frequent storms and total darkness for over three months. However, throughout the nine months the schedule of the scientific work was maintained. The station also had a definite share in the success of the first two trans-polar flights, as it had previously been decided that no attempts should be made until a base could be established near the Pole for weather reports and for emergency landing purposes.

The extent to which radio communica-

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TENT OF THE SOVIET EXPEDITION

BEING PACKED WITH ICE BY I. PAPANIN, CHIEF OF THE WINTERING PARTY.

tion was used proved one of the truly remarkable aspects of the expedition. When the windmill generated enough electricity for continuous operation, a constant stream of messages was transmitted and received. For instance, on January 1 a total of 6,754 words was sent out. Accounts of the daily happenings were dispatched all over the world, presenting the humorous incidents as well as the observations and the problems and dangers of the work. The men talked with their families thousands of miles away and listened to radio broadcasts of all descriptions.

It had not been expected that the ice-floe would remain in one place, since the existence of the great Arctic current was known before the station was established. However, it was not known exactly how currents and winds affect the ice near the Pole. For although Nansen's ship, the *Fram*, had drifted from 1893 to 1896 across the Arctic Sea, it had not approached nearer than 280 miles from the Pole. From the moment the station was established in May, 1937, though the drift was in zigzags, the unmistakable trend was in direction of the North Atlantic. At first the southward progress was slow and occasionally was reversed, but in the seventh month it began to be more rapid, until in the last month the camp was moving southward at the rate of 25 miles per day. The detailed observations made during this drift shed light not only on this vast current itself but also on the general circulation of the waters of the Arctic Sea and the influence of the great northward-flowing counter-current, the Gulf Stream.

The emergency rescue of the party from the ice was necessitated by the increasingly rapid drift to the south. It had been thought possible that the station might continue to operate for a year or more and that physical contact with it might not be necessary until the spring of 1938. Late in 1937, however, as the station drifted near the coast of Greenland, it was realized that an emergency might occur earlier than expected, due to the rapidly converging currents and severe polar storms which were endangering the stability of the ice-floe. On February 1, the floe suddenly began to split up and by the next day it was reduced in size to about 150 by 210 feet. Rescue operations were then hastened.

As in the rescue of the Cheliuskin expedition in 1934, air and sea forces were being mobilized in the meantime for coordinated action. In January the small hydrographic vessel, *Murmanets*, had sailed for the Greenland Sea to conduct observations of weather and ice conditions. On February 3 and 7 two small ice-breakers, the *Taimyr* and *Murman*, sailed, followed on the ninth by the USSR's second largest icebreaker, the *Yermak*, all equipped with planes. Several large planes equipped for possible long over-sea flights to the ice-floe were being prepared, and the Soviet Union's largest dirigible was on a test flight to participate in the rescue when it crashed. At the same time land parties, under Norwegian and Danish direction, began work on the east coast of Greenland.

After encountering severe winter gales, the *Taimyr* reached a point 20 miles from the polar station on February 13 and the *Murman*, penetrating the ice from another direction, came in sight of the station two days later. On February 16, after several attempts, a plane from one of the icebreakers landed at the station, establishing the first physical contact since June 6. Finally on February 19 the *Taimyr* and *Murman* reached a point near the station and took aboard the four scientists and their dog, as well as all the scientific records and equipment.

The establishment of more such drifting stations may follow as a result of the success of this expedition in contributing to the program of study and conquest of the Soviet Arctic. Already Soviet scientists have discussed plans for studying the area "on the far side of the Pole"—that is, in the North American sector, which now remains the least known part of the Arctic.

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